

A11103 001372

NIST  
PUBLICATIONS

NBSIR 88-3092

# SYSTEM FOR MEASURING OPTICAL WAVEGUIDE INTENSITY PROFILES

---

---

Lee E. Larson  
Donald R. Larson  
Robert J. Phelan, Jr.

National Bureau of Standards  
U.S. Department of Commerce  
Boulder, Colorado 80303-3328

August 1988

QC  
100  
U56  
88-3092  
1988  
C.2



Stimulating America's Progress  
1913-1988

**NATIONAL INSTITUTE OF STANDARDS &  
TECHNOLOGY**  
**Research Information Center**  
**Gaithersburg, MD 20899**

NBSIR 88-3092

NBSC  
QC100  
US6  
NO. 88-3092  
1988  
C.2

# SYSTEM FOR MEASURING OPTICAL WAVEGUIDE INTENSITY PROFILES

---

---

Lee E. Larson †  
Donald R. Larson  
Robert J. Phelan, Jr.

Electromagnetic Technology Division  
Center for Electronics and Electrical Engineering  
National Engineering Laboratory  
National Bureau of Standards  
Boulder, Colorado 80303-3328

† On leave from Denison University  
Physics Department, Granville, OH 43023

August 1988



---

U.S. DEPARTMENT OF COMMERCE, C. William Verity, Secretary

NATIONAL BUREAU OF STANDARDS, Ernest Ambler, Director



## Contents

	Page
1. Introduction .....	1
2. Operation .....	3
3. Construction .....	7
4. System Tests .....	9
5. Software .....	12
6. References .....	17
Appendix A: Drawings of Parts .....	18
Appendix B: List of Commercially Available Parts ...	30
Figures .....	32



## System for Measuring Optical Waveguide Intensity Profiles

Lee E. Larson\*, Donald R. Larson, Robert J. Phelan, Jr.

National Bureau of Standards  
Electromagnetic Technology Division  
325 Broadway  
Boulder, CO 80303-3328

We have developed a computer controlled system to measure the intensity profile of optical waveguides. Knowledge of the intensity profile provides an indication of the shape of the waveguide, and therefore the degree to which light can be coupled to the guide from an optical fiber. This report describes the construction and operation of this system.

Key words: computer control; coupling; mode intensity profile; optical fiber; optical waveguide

### 1. Introduction

The Coupling Efficiency Measurement System (CEM) was developed to measure the intensity profiles of optical waveguides. Knowledge of the intensity profile gives an indication of the shape of the waveguide, and therefore the degree to which light can be coupled to the guide from an optical fiber, at least qualitatively.

We perform an entrance face scan with this system, where the incoming radiation is focused to a small spot and then moved around on the entrance face of the waveguide. All the light from the output is collected and directed to the signal detector. A plot of the output signal vs position of the entrance spot provides the intensity profile. An entrance face scan gives results which are identical to the more familiar near-field exit face scan[1].

\*On leave from Denison University, Physics Department, Granville, OH 43023

In principle if waveguides supporting many optical modes are measured, the intensity profile closely matches the index of refraction profile [1]. If single mode waveguides are used, the index profile can be derived from the mode profile [2,3]. Here, however, our primary interest is in measuring the profiles to assess the efficiency of coupling light from a fiber into a waveguide.

A schematic of the system is shown in figure 1. It consists of four subsystems: Entrance Optics, Stage, Exit Optics, and Detection System. The Entrance Optics consists of (a) a source of light (He-Ne laser at the moment; at a later time laser diode sources at 750 nm, 1.3 and 1.5  $\mu\text{m}$  may be added), (b) a beam splitter which sends a portion of the incident light to a reference detector, (c) a chopper so that lock-in detection can be used, (d) a spatial filter, and (e) a microscope objective which focuses the incoming radiation to a small spot on the waveguide face (endfire coupling). The spatial filter and focusing optics are mounted on a single-axis stage and can be moved in the direction of beam propagation. This stage makes it easy to accommodate waveguides with different physical dimensions. Other components in the Entrance Optics subsystem are rigidly mounted to an optical breadboard.

The Stage has three controllable axes, each one of which can be moved with steps as small as 0.05  $\mu\text{m}$ . This stage holds the waveguide being tested as well as the Exit Optics subsystem. In operation, we move the waveguide and Exit Optics around in the fixed input beam, accomplishing an entrance face scan. This stage is fully computer controlled.

The Exit Optics subsystem has: (a) a microscope objective to collect the light which is guided by the waveguide, (b) an adjustable aperture to eliminate scattered and unguided light, and (c) a detector. This system is mounted on a small manual 3-axis stage which is fastened to the computer controlled stage. This small stage allows the exit optics to be focused and aligned with the waveguide.

The Detection System consists of two detectors, one to measure the dc reference signal, the other to measure the chopped radiation which has been guided by the waveguide. For 633 nm measurements, these are Si photodiodes. The detectors must be changed to make infrared measurements above 1  $\mu\text{m}$ . The currents generated by the two detectors are converted to voltage signals by op amps wired as current to voltage converters. These voltage signals are sent to a lock-in amplifier. When the lock-in amplifier is run in the "ratio" mode, it divides the chopped input signal by the dc reference signal and provides this ratio as its output. The effect of using this ratio mode is to eliminate the dependence of the results on the source intensity. We found in the course of our testing that, despite using this procedure, noise with relative intensity of about 1% was still present when the source was a He-Ne laser. Replacing the He-Ne source with a collimated laser diode operating at 750 nm reduced the noise by about a factor of 5. Data from the lock-in amplifier are sent to the control computer over the GPIB bus.

To use the system, the waveguide is mounted on its holder, and the stages are moved manually until light is coupled through the guide and its intensity is maximized. Then the computer moves the stage in a grid pattern, scanning the entrance beam over the face of the waveguide and recording the intensity of the coupled light with the lock-in amplifier. Data are written to a disk file, and are processed in a separate operation to provide a graphical output of the intensity profile.

The system has other uses. We have used it to measure a pinhole, and have looked at intensity profiles from a single mode optical fiber (both of these measurements were made while we were testing the system). We also used it to measure the intensity variations of light from a fiber as the exit end of the fiber was moved over dimensions of about 20 mm, to see if the power coupled through the fiber varied as the curvature of the bends was changed.

With the substitution of a fiber coupler for the entrance objective and holder, the system can be used to pigtail fibers to waveguides. The fiber will be held stationary while the substrate is moved around to maximize the coupling of the light. Then the fiber will be fastened to the waveguide with uv cured epoxy. At the moment angular positioning of the fiber must be done manually.

## 2. Operation

We assume that the system is set up: cables are connected to the computer, optics are set up and aligned, etc. If the system is not set up, refer to Section 3, Construction.

The following sign conventions and definitions will be used throughout this report. As viewed along the direction of light travel (looking at the entrance face of the waveguide), the X direction is horizontal with positive to the right, the Y direction is vertical with positive up, and the Z direction is along the optical axis, with positive away from the laser.

The following operating instructions are written specifically for the hardware we chose for the system. This has been done solely for the convenience of the operator. In most cases, other similar components could be chosen which would perform as well. If different components are used, then these operating instructions must be altered to match the hardware selected. We do not imply by our use that the hardware chosen is best for the purpose, nor do we endorse or recommend it.

1. Turn the system on. Turn on the power to the laser, chopper, detector amplifiers, computer controlled stage, lock-in amplifier, and computer.
2. From the DOS prompt on the computer, run the program NANOMOVR. A "bootable" disk is available for a floppy-based system; this disk is labelled NANOMOVR. In a hard disk system, change to the proper subdirectory and start the program.

3. Follow the prompts on the screen. When asked if you want to unpark Nanomovers, answer Y(es). To unpark all Nanomovers at the same time, press the F4 function key followed by U(npark).

4. The stage screen should now appear. When choices appear at the top of the screen, press M (for move).

5. Install the substrate. In general, it should be centered in the holder, or be offset from the stage center in the +X direction. (The travel of the output optics is limited in the direction toward the stage; it will be impossible to align the output optics with a waveguide which is too far in the -X direction.)

6. The next step in the operation of this system involves moving the computer controlled stage. The stage is moved by pressing keys on the computer keyboard. The X axis is controlled by the columns of letter keys at the left edge of the keyboard. The Q and W provide fast - and + motion, the A and S provide medium speed - and + motion, and the Z and X provide slow - and + motion. The Y axis is similarly controlled by the E-R, D-F, and C-V keys. The Z axis is controlled by the T-Y, G-H, and B-N keys.

The 4 key sets all three stages to a reasonable default position, and the 3 key sets all three stages to 0. **CAUTION: Be certain when using the 3 or 4 keys that the stage will not hit parts of the fixed system. TO STOP THE STAGE AT ANY TIME, PRESS THE SPACE BAR.**

7. Couple light through the waveguide. In general this procedure is easiest with the chopper turned off. Set up a card to use as a screen in the vicinity of the output optics aperture and focus the output optics to give a sharp image of the end of the substrate. Focus the incoming light onto the entrance face of the substrate. Coarse focus can be accomplished with the manual input stage. Use the microscope provided to view the entrance face of the waveguide. This will be an aid in focusing the light on the entrance face and in locating the waveguide.

Now move the stage as outlined in Step 6 until light travels through a waveguide. In general, the Y position is set correctly if light just grazes the surface of the substrate. As the computer controlled stage is moved in the X direction, the focusing optics must be moved manually so as to keep the two objectives aligned. Light coupled through a waveguide shows up as a small bright dot on the screen.

Once the waveguide has been found, remove the screen, and let the light travel through the aperture to the detector. The image can be lined up so it passes through the aperture to the detector by adjusting the manual stage holding the output optics. Normally the waveguide image should be focused between the aperture and the detector, so that the image nearly fills but does not overflow the detector. Then the aperture should be closed to just block the stray radiation. Now turn on the chopper. We have made most measurements with a chopper frequency of about 500 Hz.

8. Adjust the lock-in amplifier so that it indicates the ratio of signal to reference voltage. If the signal appears noisy, check the size of the dc reference signal. It should be in the range of 1 to 2 volts. (If the reference signal is too small, the discrete nature of the A/D converter will make the ratio signal appear noisy; if the reference signal is too large, the signal amplifier will overload when a reasonably large output is requested.) If the reference signal is not in the correct range, adjust the feedback resistor on the reference amplifier until it is correct.

Once the lock-in amplifier is adjusted, peak the signal by making small motions in the computer controlled stage. The X and Y positions should be adjusted with the Z-X and C-V key pairs, a single step at a time until the lock-in amplifier signal is maximized.

(These fine-adjust keys allow the stage to be set with 0.1  $\mu\text{m}$  resolution. In addition, the anti-backlash feature is enabled for these keys. The anti-backlash feature is disabled for the medium and coarse adjustments to make continuous motion smoother. The motions used under program control have the anti-backlash feature enabled; therefore for consistency between keyboard adjustment and program adjustment, the final X and Y motions in the maximizing process should always be made with the fine-adjust keys. This is not so critical for the Z motion; the Z motion is not adjusted by the program, and the depth of field of the focusing optics is a couple of  $\mu\text{m}$ , so small inaccuracies in the Z motion will not affect the results.)

9. Press the F10 function key to get back to the main menu. Press P for program, select the default BASIC by pressing `<RET>`, and interpreted BASIC will start. Type `RUN CEM` to start the control program. The program requests the extent of the X and Y motions, the number of steps to use, the lock-in amplifier time constant, and the number of readings to signal average. (The program waits a settling time of twice the value you provide for the lock-in amplifier time constant. If the signal is noisy, the lock-in amplifier can be read more than once at each data point, and the results averaged.)

The program will now start, and "quick look" data will be graphed on the screen. The reading in the lower left corner of the screen is the actual data from the lock-in amplifier.

After all data are taken, the program gives an option to save the information to a disk file. Follow the screen prompts carefully. The data file is in the format of a SURFER GRD file and can be used directly by the program SURFER for drawing contour lines or intensity profiles of signal voltage.

10. To get back to the Nanomover screen, type `SYSTEM`. To quit, from the Nanomover menu type `Q`, and when asked if you want to park Nanomovers, respond with `Y(es)`, press function key `F4` to choose all motors, and press `P(ark)`. ALWAYS TERMINATE OPERATION AS DESCRIBED ABOVE SO THE NANOMOVER SYSTEM WILL NOT LOSE ITS ORIENTATION.

11. Software program SURFER can be used to draw contour lines (Section 11.1) or intensity profiles (Section 11.2) of signals.

11.1 Contour Lines. On a computer which has SURFER loaded, get into the SURFER subdirectory and type **TOPO FILNAM** where FILNAM is the name of the data file containing a run of data. FILNAM should include disk drive and/or subdirectory. An extension of GRD is understood.

Information presented on the screen includes the minimum and maximum Z signal. To draw 10% contour lines, compute 10% and 90% of the difference between minimum and maximum Z values. Then select **Level**, fill in Minimum contour with the 10% number, Maximum with the 90% number, and Interval with the 10% number. Press **ESCAPE** to get back to the main menu.

At any time a screen graph can be seen by pressing function key F2.

Some useful options include:

**Output:** Sends output to plotter. Use defaults; change last choice to Yes.  
**Title:** If a title is desired, select **Title** option and enter.  
**Grid:** Select to turn grid lines on if desired.  
**Scale:** Used to change the size of the plot.  
**Conlines:** Allows contour lines to be labelled, changes smoothing options.  
**Equip:** Used to change plotter type, screen colors, etc.

Special keys and Function keys have the following uses:

**ESCAPE:** Back up one menu choice; return to next screen when viewing graph.  
**F1:** Help  
**F2:** View display on screen  
**F3:** Return to Main Menu  
**F4:** Stores highlighted value as a default for future graphs.  
**Shft-F4:** Stores all current settings as defaults for future graphs.

In general, defaults have been stored so that a minimum number of changes need to be made for good displays with data from the CEM system.

11.2 Intensity Profiles. To draw intensity profiles, get into the SURFER subdirectory and type **SURF FILNAM** where FILNAM includes drive and/or path information.

Function key F2 will draw the intensity profile on the screen.

Useful options include:

**Base:** Determines whether to draw base. Default is Base Off.  
**Title:** Use this option to add a title to the plot.  
**Axes:** Plot and label axes. Default has X and Y axes plotted. Titles can be added, and Z axis can be plotted as well.  
**Size:** Change the size of the overall plot, and change scale of Z axis relative to X and Y axes. Default fills a normal sheet of paper.

Output: Make a hard copy of intensity profile. Use the defaults on the menu, but answer Yes to last question.

The special keys and function keys have the same meaning as in TOPO, and are described in the previous section.

### 3. Construction

The CEM System is made up of commercially available components wherever possible, to keep custom machining to a minimum. Custom made parts consist of 11 different types: detector holders (2), substrate holder, three different thickness spacers, five different optical mounting platform parts and table legs (4). Drawings of these parts are included in Appendix A. Letters in curly brackets refer to the item in the drawings. A list of commercially available parts to make up the remainder of the system is included as Appendix B. This list is provided as a convenience to others building such a system. In the following description, the numbers in curly brackets refer to the numbers on the list of parts.

To make the construction details clear, we describe the system as a combination of subsystems.

The optical axis for the system was set at 5.5 inches, determined as a convenient working height for the computer controlled stage.

3.1 Optical Platform. The system is built on a 2 by 4 foot optical breadboard (1). This breadboard is not vibration isolated, and providing this isolation could possibly improve the system resolution.

3.2 Source and Entrance Optics. These parts are assembled as shown in figure 2. The system is designed to hold several sources (lasers) of different wavelengths, and to have a beam switching mirror which will easily let light from any one of the sources into the entrance optics. However, at this time the only source used is a 1 mW helium-neon laser (2). This laser is mounted in an adjustable mount to allow easy height adjustment (3). The mount is spaced from the post by a spacer (A) to put the beam on the correct optical axis.

A beam splitter (4) is used near the laser to send a portion of the light to a reference detector (B),(5). The output of this detector is sent to the lock-in amplifier and is used to ratio the main signal to remove noise due to laser intensity fluctuations. The light is then sent through an optical chopper (6) so that lock-in detection can be used.

The entrance optics are mounted on a custom made mounting plate (C) which is fastened to a one axis stage (7). This stage is in turn mounted on an optical table (D),(E) to set the optical axis at the correct height. Two components are fastened to the mounting plate: a spatial filter assembly (8) which is raised by a spacer (F) to the correct optical axis height and a

microscope objective holder {9}. Three different microscope objectives {10} with powers of 20X, 40X, or 60X can be used to couple light into the waveguide. The objective holder and spatial filter are mounted at approximately the "tube length" of the objectives apart, a distance of 160 mm.

3.3 Computer Controlled Stage and Substrate Holder. Refer to figure 3. A three axis precision computer controlled stage {11} is used to move the substrate and exit optics in the entrance beam. A bracket assembly {G},{H} which fastens to this stage supports the substrate holder {I} and the exit optics. A spacer {J} is placed between the bracket assembly and the substrate holder so that it is properly positioned. The substrate being studied is gently clamped to the holder using 1/2" diameter Teflon washers which are tightened against the substrate by thumbscrews. The bracket assembly also supports the exit optics described in the next section.

3.4 Exit Optics. The exit optics are fastened to a mounting plate {K}, which is held to the bracket assembly by a small manual 3-axis stage {12}. The manual stage allows the optics to be aligned and focused relative to the substrate. When the measurements are being made, however, the exit optics assembly does not move relative to the substrate holder. The computer controlled stage moves both the substrate and the exit optics as a fixed unit. The arrangement is illustrated in figure 3.

There are four components which make up the exit optics. A 10X microscope objective {13} held in an objective holder {14} is used to form an image of the exit face of the waveguide. An aperture {15} is used to eliminate light not guided by the waveguide, and a detector {B},{16} is used to measure the signal. The objective lens is mounted near the substrate end of the mounting plate, and the detector is mounted near the far end. The aperture is mounted approximately in the center. The horizontal Z position of these components is not critical. The X and Y locations of the detector and aperture assemblies are adjustable, and must be set so that light from the waveguide falls squarely on the detector.

3.5 Electronics. The signals from the detectors are amplified by op amps connected as shown in figure 4. The op amps are powered by a small modular +/- 15 volt power supply. The signal from the reference detector is wired to the reference signal input of a lock-in amplifier {17}, and the output of the signal detector is sent to the main lock-in input. The output of the lock-in is sent to the control computer over the GPIB bus.

The computer controlled stage must be interfaced to the control computer. See the stage manual for instructions.

3.6 Microscope. A microscope {18} is used as an aid to coupling the light into the waveguides. Its base sits on an unused part of the optical breadboard, positioned so that its head can be placed over the entrance face of the waveguide.

3.7 Setup. First, all components should be arranged as described in the previous sections. The laser is polarized; if its plane of polarization is important to the measurements to be made, rotate the laser in its mount until the beam has the proper orientation. The direction of polarization is indicated on the back of the laser. Place the chopper in the beam as shown in figure 2; do not run it, but place the blade so that light passes down through the system.

Next, align the input optics. With the entrance objective and spatial filter elements removed, align the laser beam so that it is level and passes through the center of the lens mounts. Then replace the lenses and spatial filter pinhole. Adjust the position of the reference detector and/or beam splitter until the reference beam falls in the center of the reference detector. Next place a card at the entrance objective holder, before the lens. Adjust the position of the pinhole until a symmetric image is present. Then adjust the focus of the spatial filter lens until the central spot is brightest and the least light is present in the diffraction rings. The position of the pinhole may need to be adjusted again to keep the image symmetric. Remove the card and check to be sure that the expanded beam from the spatial filter is centered on the entrance objective. If it is not, slight adjustments may need to be made to the position of the laser. Once the spatially filtered light is centered on the objective, a good image should be formed at the position of the substrate entrance face. Check the quality of the out-of-focus image on a card; be sure it is symmetric and evenly illuminated. Repeat this entire procedure if necessary.

Connect the detector amplifiers to the detectors and connect the power to the amplifiers from the power supply. Connect the reference detector output to the lock-in reference detector input (ADC 1 on the EG&G 5209), and connect the signal detector output to the main lock-in input. Connect the computer controlled stage as described in the stage manual. Motor 1 is wired to the top connector, 2 to the center one, and 3 to the bottom. Plug in all ac power cords.

Install the substrate and locate a waveguide as described in Section 2, Operation. Once the waveguide is guiding light, adjust the manual stage position until the light passes through the center of the aperture. Adjust the focus of the exit objective using the Z axis of the manual stage until the beam focuses between the aperture and the detector. Then adjust the detector mount until the image is centered on the signal detector. Once this procedure is complete, turn on the chopper.

The system should now be set up for most measurements.

#### 4. System Tests

We performed a series of tests designed to show that the system is functioning and to explore its limitations. These tests are described in the following sections. Two types of information are presented in the figures:

a) contour plots of intensity vs X-Y position with contour lines referenced to the maximum signal and drawn at 10% intervals. b) relative intensity profiles as a function of X-Y position.

4.1 Initial Test Using a Pinhole. We inserted a 25  $\mu\text{m}$  pinhole in the system at the waveguide location, and scanned it. The entrance objective had a power of 20X and a NA of 0.4. The results are shown in figures 5 and 6. Figure 5 shows the intensity contour plot and figure 6 displays the intensity profile. The step size was 1  $\mu\text{m}$ . The data are basically what we expect for a pinhole source of this diameter, confirming that the movement of the stages is at least roughly correct. By looking at the most dense distribution of contour lines, we see that the beam size of the entrance beam is about 1  $\mu\text{m}$ .

4.2 Single Mode Fiber. We measured the intensity profile of a fiber which supports a single mode at 633 nm. The advertised core size is 5  $\mu\text{m}$ . For our first attempts we used a piece of fiber about 2.5 cm long. The results were difficult to interpret, particularly when the entrance light was focused with a high NA lens. After noticing that the entire fiber assembly was glowing from end to end, we decided that the difficulties were possibly caused by cladding modes which had not radiated away and which were fairly sizeable in comparison with the core signal. We then replaced the short fiber with a piece about a meter in length clamped to the waveguide holder at each end and looped around the apparatus. Results with the longer fiber were much closer to what we expected.

Since the waveguides we use are all relatively short, this experience suggests that we must be very careful to use the aperture in the exit optics system to mask light from outside the guide. In addition, the entrance objective should have a relatively low NA. A NA of about 0.4 is a good compromise between having the spot size small (about 1  $\mu\text{m}$ ) and not having excessive radiation outside the waveguide.

Figure 7 shows the intensity contours when the system was incorrectly focused. A similar plot with the system correctly focused is shown in figure 8. The pattern is circular, and the diameter of the 10% contour line is just over 5  $\mu\text{m}$ . The pattern of the out-of-focus plot is broader than the one which is correctly focused.

The profile cross section of a single mode fiber is often Gaussian. Figures 9 and 10 illustrate the horizontal and vertical profile cross sections, with a Gaussian function superimposed. There are small variations, but in general the fit is quite good.

4.3 Waveguides. We measured intensity profiles for several potassium ion-exchanged glass channel waveguides. These were all on a single substrate. The results are shown in figures 11-15. In addition to the intensity profiles, corresponding mechanical surface profiles near the ends of the guides are shown. The potassium ion-exchange process used to increase the refractive index of the glass also causes a slight swelling of the glass.

For the mechanical surface profiles, the horizontal axis is in  $\mu\text{m}$ , and the vertical axis is in angstroms. The surface of the guides are readily apparent in the intensity profiles; the spread in contour lines above the surface is due in part to the finite size of the spot on the entrance face.

The intensity profile shown in figure 11 indicates that the waveguide is at an angle relative to the X axis. We believe this is real, and that there is a ripple in the glass in this region. The ripple does not show up in the surface profile, because the surface profilometer electronically levels the surface.

The most interesting observation relates to the symmetry of the guides. The intensity profiles for guides shown in figures 12 and 15 are nearly symmetric, as are the surface profiles. In cases where the intensity profiles are asymmetric (figures 11, 13, 14) however, the surface profiles taken near the ends of the guides are also asymmetric. In fact, for the guide shown in figure 14, both the intensity profile and the surface profile show two peaks near the center of the guide. At least on a qualitative level, then, the mechanical shape of the guide and the "optical shape" are similar.

4.4 Intensity variations of light from a fiber. In experiments we have designed to measure the response uniformity of detectors, we plan to couple light into a fiber, and then to move the fiber around the detector surface while we record response as a function of surface position. The question arises as to how much variation is caused by changing the bends in the fiber during the course of the measurement. We have used the CEM system to measure this variation.

We used an auxiliary laser and fiber coupler to couple light into the fiber. These components were rigidly mounted to the optical breadboard. The beam splitter, reference detector, and chopper were moved to this auxiliary beam and serve the same purposes here as for the usual measurements. The exit end of the fiber was clamped to the waveguide holder, and the output radiation was directed to the detection system.

We moved the exit end of the fiber over a 22 by 22 mm square pattern and recorded intensity as a function of position. The results are shown in figures 16-21. The contour plots have lines drawn at 20% intervals between the minimum and maximum signal levels.

The source for the results shown in figures 16-18 is a helium-neon laser. The maximum variations from the mean value are of the order of 1%. The source for the results in figures 19-21 is a laser diode which operates at a wavelength of 750 nm. With this source the output is much more stable, with maximum variations of about 0.2%. When comparing the two dimensional intensity profiles shown in figures 17 and 20, note the change in the vertical scale.

Our results indicate that the variations, at least above the 0.2% level, are due to the source rather than the variations in fiber loss due to changes in the bends.

4.5 Stage Motion. In order to test the accuracy of the stage motion, we set up a laser interferometer and compared the interferometer readings with the positions to which the stage was directed by the computer. We tested only the Y axis stage which provides the vertical motion. Since this stage is under the most mechanical load, it should give us a worse case indication of the accuracy.

Extensive tests allow us to draw the following conclusions. (a) The stages used in this system have an automatic scheme for removing backlash termed the Lost Motion (LM) control by the manufacturer. The direction and extent of stage motion to remove backlash can be controlled by the operator. At least for this stage, much better results are obtained with the LM direction negative. (b) An LM value of 2 (20  $\mu\text{m}$ ) seems adequate. Nothing is gained by increasing this value. (c) A relatively low stage velocity is marginally better than a high one.

One of the major limitations to our tests seem to be temperature changes in the room. The stage manufacturer notes that temperature changes causing length changes in the screw constitute a major source of error. This is confirmed by Figures 22-24 which show the change in interferometer readings when the stage was not moving, taken during the morning when the temperature of the laboratory was noticeably increasing. The 500 readings were taken over a period of about 10 min. Figure 22 shows that the path length changed about 0.5  $\mu\text{m}$  over this time. To get a measure of errors between adjacent readings and between those which are 20 units apart, we drew the histograms shown in figures 23 and 24. Figure 23 shows that, typically, adjacent readings differ by less than 0.1  $\mu\text{m}$ . This is essentially a measure of the noise in the measurement system, since the stage was not moving. The data shown in figure 24 are an indication of the drift of the system with time. Subtracting points which are 20 readings apart results in a significant number of cases where differences are up to 0.3  $\mu\text{m}$ .

Typical stage data are shown in figures 25-27. We see maximum errors over one turn of the micrometer screw (500  $\mu\text{m}$ ) of about 1  $\mu\text{m}$ . Figure 26 shows that most adjacent points representing stage motion of 1  $\mu\text{m}$  show errors less than 0.1  $\mu\text{m}$ , with a smaller but significant number with errors of up to 0.2  $\mu\text{m}$ . For readings over 20  $\mu\text{m}$ , a typical width of a waveguide scan, figure 27 shows errors up to 0.3  $\mu\text{m}$ .

Our conclusions from a large series of measurements such as those just described is that the stage meets our requirements for accuracy.

## 5. Software

The software to run the CEM system consists of two programs, a compiled program to run the computer controlled stage which is supplied by the stage manufacturer, and an interpreted BASIC program which drives the system, acquires the data, provides graphics for a "quick look" at the data, etc.

5.1 Nanomovr. This is the compiled program which operates the stage. The instructions for its operation are given in an earlier section of this report.

There are sixteen different configuration possibilities. These can be used to drive up to sixteen different motors, a single motor in sixteen different ways, or any combination. In our case we drive three motors in five different ways, leaving one configuration possibility unused. The stage manufacturer calls each configuration option an "axis".

A summary of the configuration options as used in this system is shown in figure 28. Each of the 16 lines in this table, beginning with "X Repeat Fast," is a brief indication of the motion expected for that particular set of options. The actual configuration for each line in this table is made by choosing Change from the menu and selecting the appropriate line from the table. Figures 29-31 show representatives menus of these options. All the choices from the table in figure 28 which move the X axis motor are shown in figures 29-31. The corresponding Y and Z choices are similar, except for Axis Name, Motor #, and values of Plus Key and Minus Key. The axis names and motor numbers are all listed in figure 28, and the Plus and Minus Key values are discussed in the OPERATION section of this report. The stage manual describes each of the parameters listed in figures 29-31 and how to choose appropriate values.

If the motor parameters are changed, they will be in force only until the program is terminated unless they are saved in an AXS file. To save parameters, choose the Files option. The parameters shown in the figures are saved in the default file NANOMOVR.AXS. This is the AXS file which is automatically loaded when the program starts.

The configuration parameters used in the BASIC acquisition program are from lines 11-13 in figure 28, labelled X Tab, Y Tab, and Z Tab. The acceleration, speed, LM control, and so on used by the BASIC program are from these parameter tables.

5.2 BASIC Driver Program. This is the program which actually does the data acquisition. A commented listing of the code written in Interpreted BASIC for a floppy disk system follows. The code for a hard drive system is very similar, except for Lines 250 and 5610 (change Hex number to &HD000), Lines 660, 670 and 1020 (screen parameters) and Lines 1060-1080 which specify the file name for stored data.

```
10 'Program CEM which is designed to run the CEM system to measure mode
20 'profiles. It uses the NANOMOVER stage and a PAR 5209 lock-in interfaced
30 'through a CEC-488 card.
40 'Written by Lee Larson, NBS, Boulder, CO 3/15/88
50 '
60 ' Initialization for NANOMOVER
70 '
80 DEF SEG=0
90 NANOMOVE=PEEK(320)+PEEK(321)*256
100 NANOSEG=PEEK(322)+PEEK(323)*256
```

```

110 NANOPOS=PEEK(324)+PEEK(325)*256
120 NANOSTAT=PEEK(326)+PEEK(327)*256
130 DEF SEG
140 'Define 3 axis variables
150 XAX=11           'X axis on front of waveguide (Motor 2)
160 YAX=12           'Y axis on front of waveguide (Motor 3)
170 ZAX=13           'Z axis, focus waveguide (Motor 1)
180 DIM Z%(100,100)
190 'Sub at 5000 (define AXIS, POSITION) moves motor.
200 'Sub at 5200 (define AXIS) reads position into POSITION
210 'Sub at 5400 (define AXIS) reads status into STAT (0 normal w/ no motion)
220 'Sub at 5600 takes a data point; returns value in Q%
230 '
240 'Initialize CEC board and Lock-in
250 DEF SEG = &HC000
260 INIT=0 : SEND=9 : ENTER=21 : TRANSMIT=3 : ADDR%=21 : LOCKIN%=9 : LEVEL%=0
270 STATUS%=0
280 Q$=SPACE$(60)
290 LENGTH%=0
300 'LOCKIN ADDRESS SHOULD BE 9 AND TERMINATOR SHOULD BE LF
310 CALL INIT(ADDR%, LEVEL%)
320 DEF SEG
330 '
340 'Now set up system for measurements
350 CLS
360 PRINT "Stage should be set using NANOMOVR menu for center of waveguide."
370 INPUT "Has this been done (Y,N) ",S$
380 IF S$="Y" OR S$="y" THEN GOTO 430
390 IF S$="N" OR S$="n" THEN GOTO 410
400 PRINT "NOT A VALID ANSWER" :GOTO 360
410 INPUT "Go back to NANOMOVR menu (Y or N) ", S$
420 IF S$="Y" OR S$="y" THEN SYSTEM
430 CLS
440 INPUT "WIDTH OF SCAN IN X DIRECTION (MICRONS) ",WX
450 INPUT "WIDTH OF SCAN IN Y DIRECTION (MICRONS) ",WY
460 INPUT "NUMBER OF POINTS ON EA LINE IN X DIRECTION ",NX
470 INPUT "NUMBER OF POINTS ON EA LINE IN Y DIRECTION ",NY
480 INPUT "TIME CONST OF LOCKIN (MS) ",TCONST
490 DELAY1= TCONST*2/1000      'Delay time is twice time const of lockin
500 INPUT "NUMBER OF READINGS TO SIGNAL AVERAGE ",NOSIG
510 INCX=WX/NX                'INCREMENT TO MOVE IN X DIRECTION
520 INCY=WY/NY                'INCREMENT TO MOVE IN Y DIRECTION
530 INPUT "PRESS <RETURN> KEY TO BEGIN TAKING DATA ",S$
540 GOSUB 5600                'Take peak value before moving
550 ZMAX%=Q%                  'Store as initial value for ZMAX%

```

```

560 SCALE=2*NY/ZMAX%           'Scale factor for data plotting
570 OFFSET=2                   'Rot factor for plot; > num plots straighter
580 'MOVE STAGE TO STARTING POINT
590 AXIS=XAX                   'X DIRECTION ON FRONT OF WAVEGUIDE
600 POSITION=-NX*INCX/2
610 GOSUB 5000
620 AXIS=YAX
630 POSITION=NY*INCY/2
640 GOSUB 5000
650 CLS
660 SCREEN 2
670 VIEW (0,0)-(719,317)
680 KEY OFF
690 WINDOW (0,0)-((NX+(NY/OFFSET)),(1.5*NY+ZMAX%*SCALE))
700 FOR Y=0 TO NY
710 AXIS = XAX
720 POSITION=INCX
730 FOR X=0 TO NX
740 GOSUB 5600                 'Get data point
750 Z%(X,Y)=Q%
760 LOCATE 25,1:PRINT Q%;
770 IF X=0 THEN PSET (X+Y/OFFSET,Y+Q%*SCALE)
780 LINE -(X+Y/OFFSET,Y+Q%*SCALE)
790 IF Q%>ZMAX% THEN ZMAX%=Q% 'Make sure ZMAX% is largest value
800 IF X=NX THEN GOTO 820     'Don't inc position after last data pt
810 GOSUB 5000                 'Move to next X position
820 NEXT X
830 IF Y=NY THEN GOTO 870     'Don't inc position after last data pt
840 AXIS=YAX
850 POSITION=-INCY              'Move to next Y position
860 GOSUB 5000
870 AXIS=XAX
880 POSITION=-WX
890 GOSUB 5000                 'Return to beginning X position
900 NEXT Y
910 'Return stages to starting point
920 AXIS=XAX
930 POSITION=NX*INCX/2
940 GOSUB 5000
950 AXIS=YAX
960 POSITION=NY*INCY/2
970 GOSUB 5000
980 LOCATE 25,1:PRINT "PRESS <RETURN> TO CONTINUE";
990 INPUT S$
1000 KEY ON
1010 CLS
1020 SCREEN 0
1030 'Save data in a file
1040 INPUT "SAVE DATA ON DISK (Y,N) ",S$

```

```

1050 IF S$="N" OR S$="n" THEN GOTO 4990 'End
1060 INPUT "NAME OF FILE (NO EXTENSION OR DRIVE SPECIFIED) ", F$
1070 INPUT "BE SURE DATA DISK IS LOADED IN DRIVE B; PRESS <RETURN> WHEN READY
", S$
1080 F$="B:"+F$+".GRD"
1090 OPEN F$ FOR OUTPUT AS #1
1100 PRINT #1,"DSAA"
1110 PRINT #1, NX+1,NY+1
1120 PRINT #1, 0,WX
1130 PRINT #1, 0,WY
1140 PRINT #1, 0, ZMAX%
1150 FOR Y=0 TO NY
1160 FOR X=0 TO NX-1
1170 PRINT #1, Z%(X,Y);
1180 NEXT X
1190 PRINT #1, Z%(NX,Y)
1200 PRINT #1,
1210 NEXT Y
1220 CLOSE #1
1230 PRINT "DATA SAVED IN FILE ";F$
4990 END
5000 'Subroutine to move position
5010 DEF SEG=NANOSEG
5020 CALL NANOMOVE(AXIS, POSITION)
5030 DEF SEG
5032 GOSUB 5400 'Check STAT; wait for motor to stop moving
5034 IF STATUS AND 1 THEN GOTO 5032
5040 RETURN
5050 '
5200 'Subroutine to read position
5210 DEF SEG=NANOSEG
5220 CALL NANOPOS((AXIS,POSITION)
5230 DEF SEG
5240 RETURN
5250 '
5400 'Subroutine to read status
5410 'A reading of 0 is when all is normal and there is no motion
5420 DEF SEG=NANOSEG
5430 CALL NANOSTAT(AXIS, STATUS)
5440 DEF SEG
5450 RETURN
5460 '
5600 'Subroutine to get data point from lockin
5602 START=TIMER
5605 IF (TIMER-START)<DELAY1 GOTO 5605 'Allow for settling time
5610 DEF SEG = &HC000
5612 B=0 'Sum of signals for signal average
5615 FOR S=1 TO NOSIG 'Take NOSIG readings for sig ave
5620 A$="OUT"

```

```

5630 CALL SEND(LOCKIN%,A$,STATUS%)
5640 Q$=SPACE$(60)
5650 CALL ENTER(Q$,LENGTH%,LOCKIN%,STATUS%)
5660 Q=VAL(LEFT$(Q$,LENGTH%)) 'DATA POINT RETURNED AS Q%
5665 Q=ABS(Q)
5666 B=B+Q
5667 NEXT S
5670 DEF SEG
5675 Q%=INT(B/NOSIG) 'Signal averaged value to return
5680 RETURN

```

A second BASIC program named CEMBACK is on the NANOMOVR disk. It is essentially the same as the one shown above, except that the scan starts at the upper right corner instead of the lower left. The only changes are the directions to increment and loops which start at the maximum value and work down rather than starting from the smallest value as is the case with CEM.

## 6. References

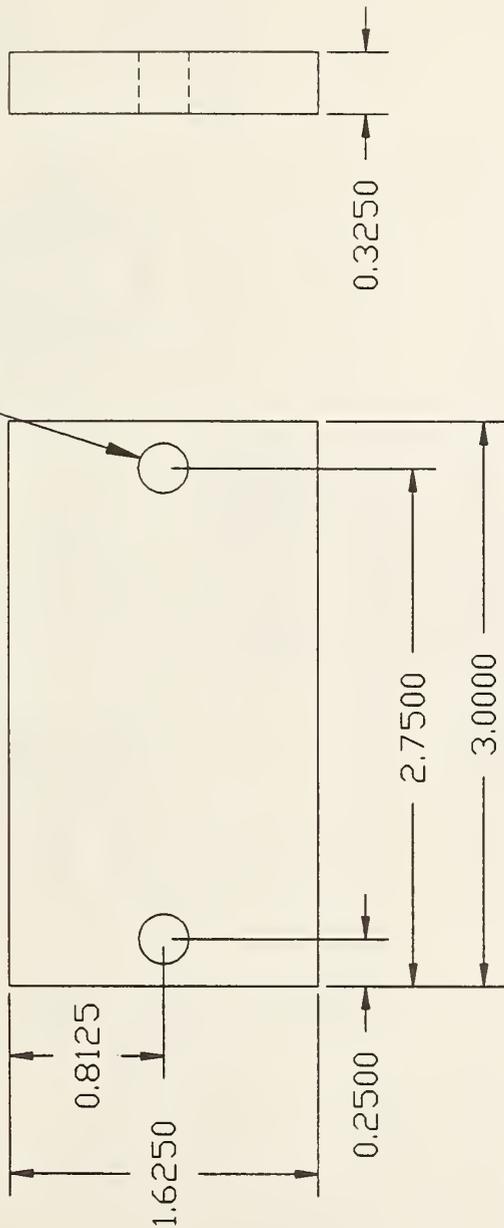
- [1] Young, M. Refracted-Ray Scanning (Refracted Near-Field Scanning) for Measuring Index Profiles of Optical Fibers, chapter 3 in Optical Fiber Characterization Nat. Bur. Stand. (U.S.) Spec. Publ. 637, V. 1; 1982 July. 200 p.
- [2] McCaughan, Leon; Bergmann, Ernest Index Distribution of Optical Waveguides from Their Mode Profile. J. Lightwave Technology LT-1: 241-244; 1983 March.
- [3] Morishita, Katsumi Index Profiling of Three Dimensional Optical Waveguides by the Propagation-Mode Near-Field Method. J. Lightwave Technology LT-4:1120-1124; 1986 August.
- [4] Kim, E.M.; Franzen, D.L. Measurement of Near-Field Radiation Patterns from Optical Fibers, chapter 3 in Optical Fiber Characterization Nat. Bur. Stand. (U.S.) Spec. Publ. 637, V. 2; 1983 October. 239 p.

## APPENDIX A

### Drawings of Parts

- A. Spacer
- B. Detector case
- C. Mounting plate
- D. Optical table
- E. Optical table
- F. Spacer
- G. Bracket assembly
- H. Bracket assembly
- I. Substrate holder
- J. Spacer
- K. Mounting plate

2x $\phi$ 0.2656"  
typ.

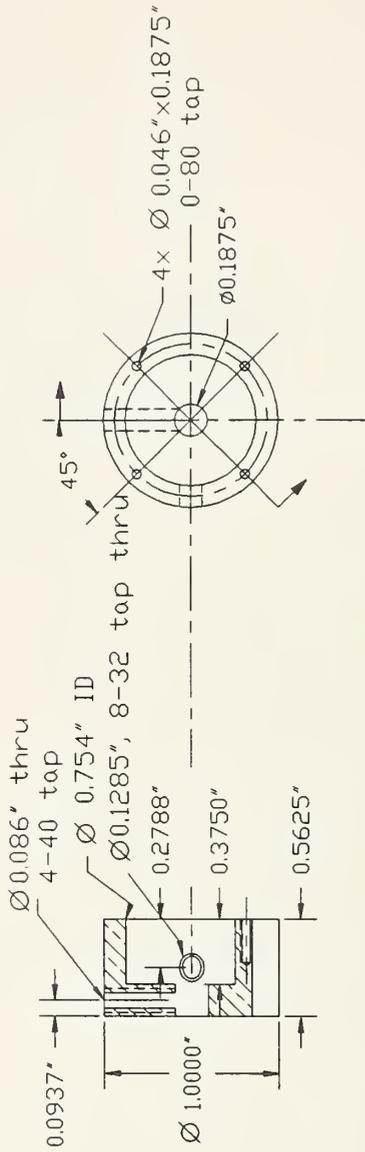


{A} Spacer

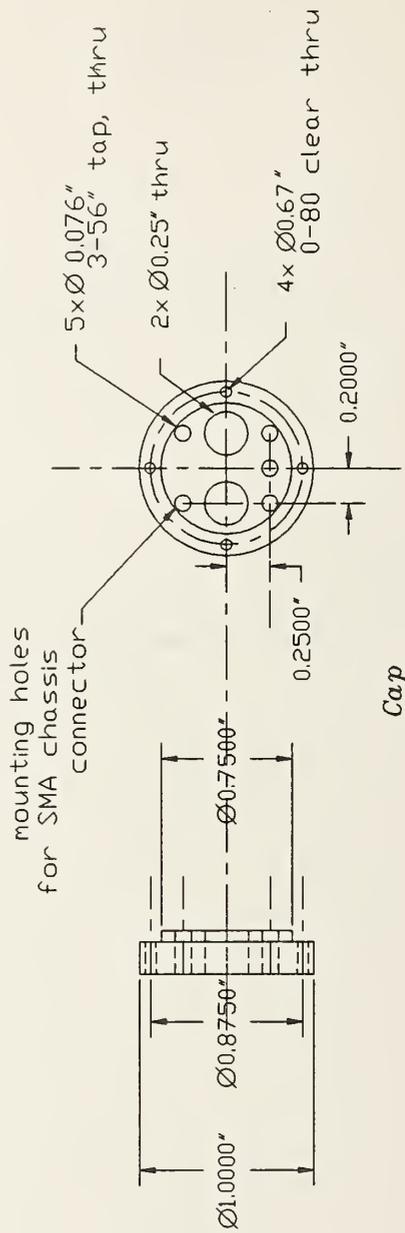
Drawn: JHL, Mat'l: al

chk: DL, Qty: 1

Date: 4 Jun 88 Surface: blk.ano



Body



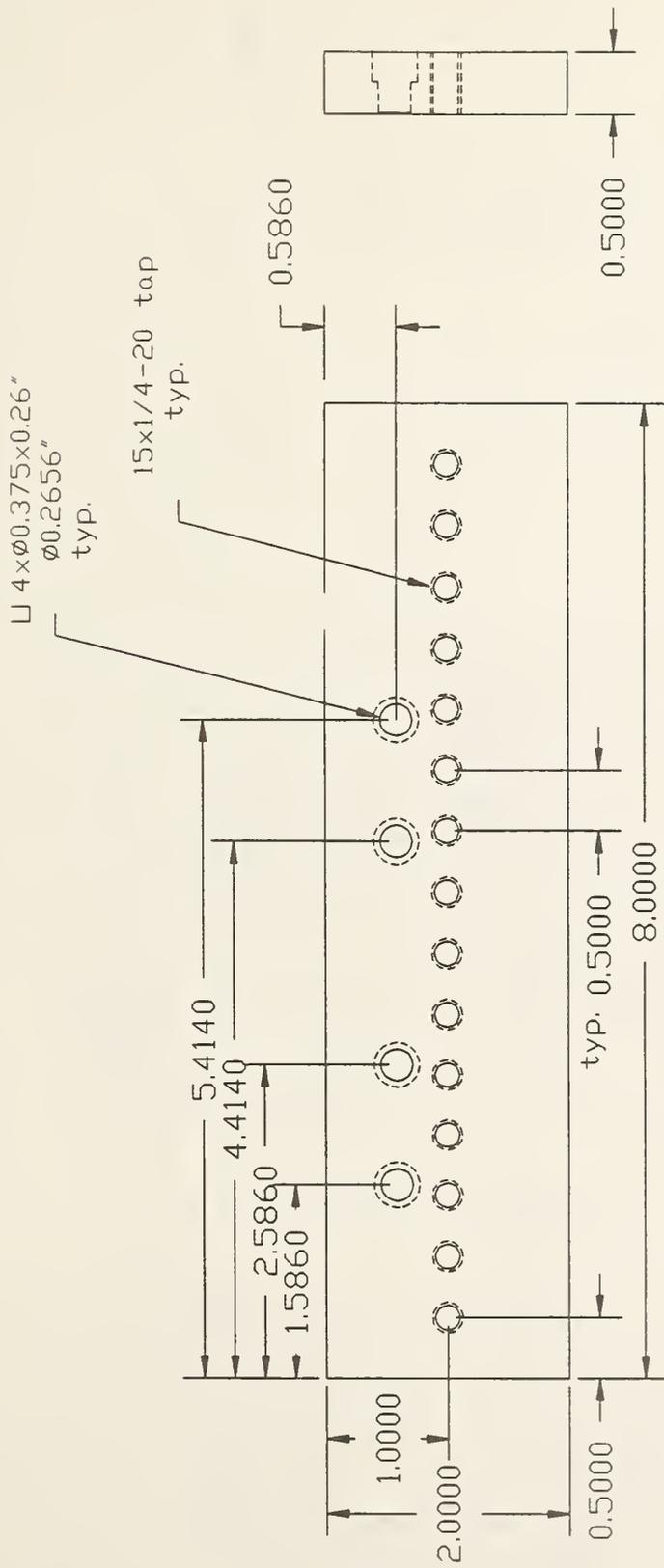
Cap

Gold plated brass

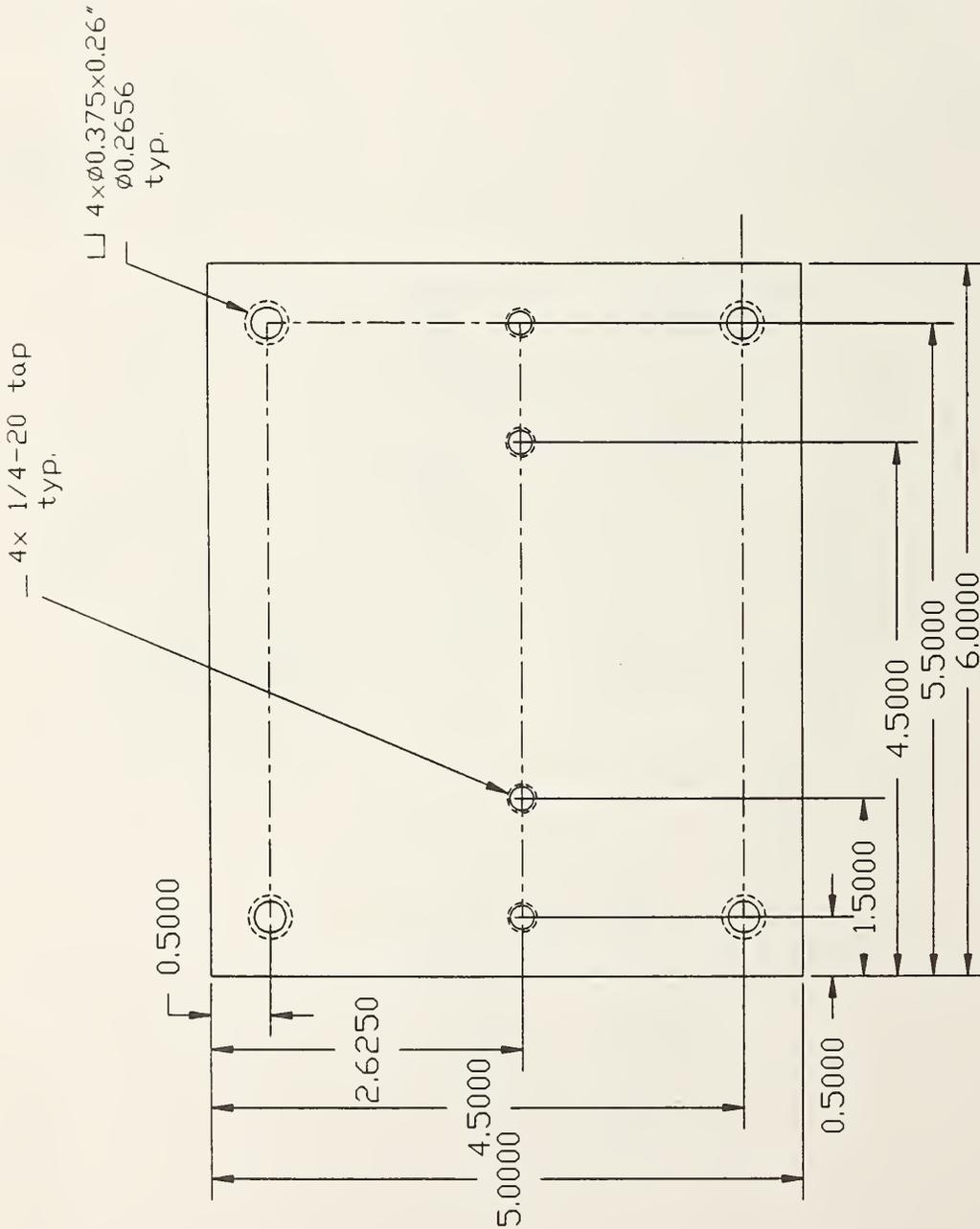
{B} Detector Case

Drawn by: JHL Date 29 Feb 88

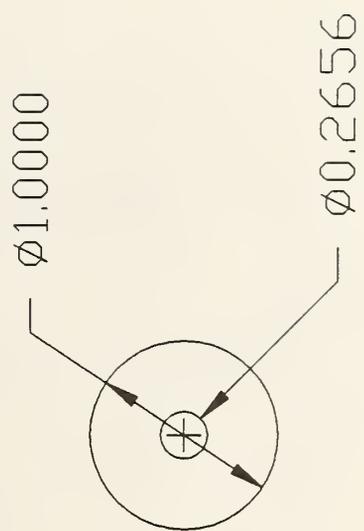
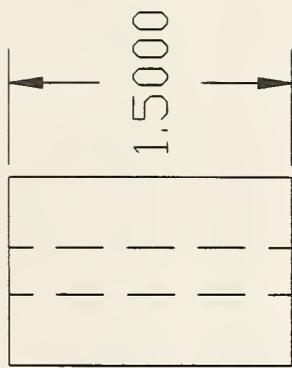
Checked: JLF Date /14/78



{C} Mounting Plate	
Drawn: JHL	Mat'l: al
chk: DL	Qty: 1
Date: 7 Jun 88	Surface: blk.ano



{D} Optical Table		
Drawn: JHL	Mat'l: al	
chk: DL	Qty: 1	
Date: 4 Jun 88	Surface: blk.ano	



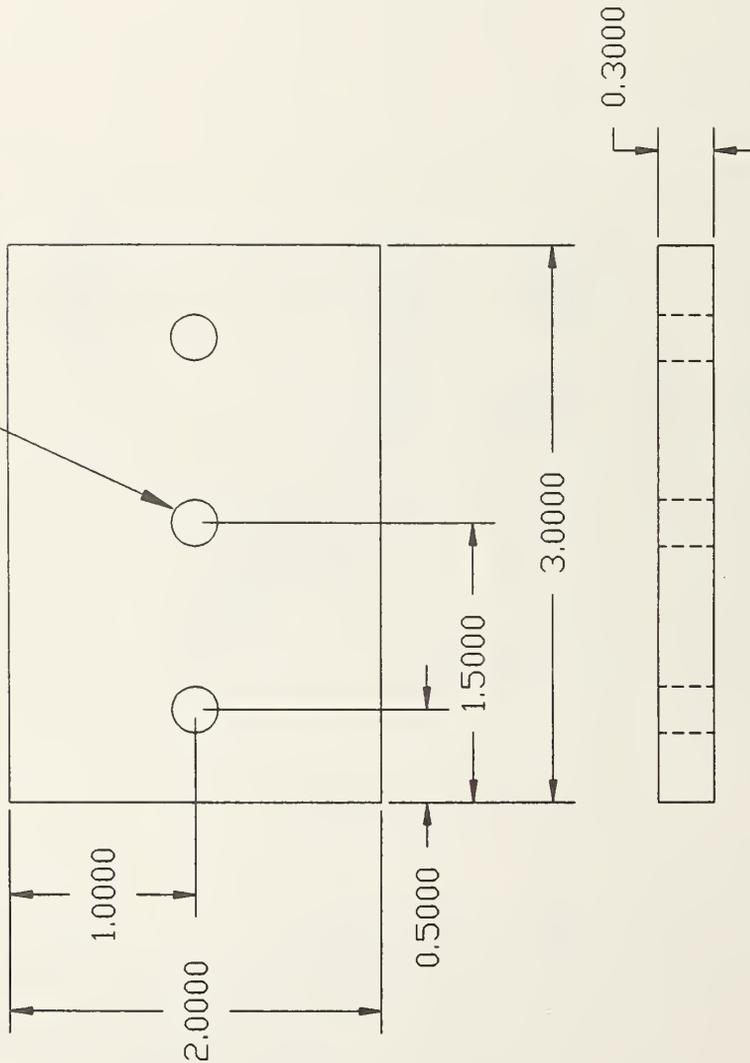
{E} Optical Table

Drawn: JHL, Mat'l: al

chk: DL, Qty: 4

Date: 4 Jun 88 Surface: blk.ano

3x $\varnothing$ 0.2656"  
typ.



{F} Spacer

Drawn: JHL. Mat'l: al

chk: DL. Qty: 1

Date: 4 Jun 88 Surface: blk. ano

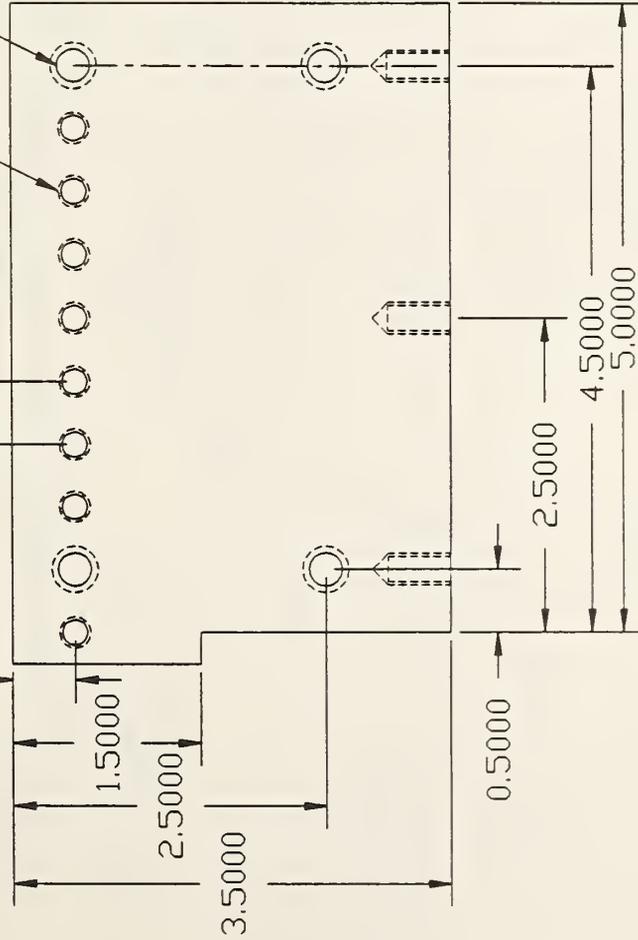
8x1/4-20 tap  
typ.

LJ 4x $\phi$ 0.375x0.26"  
 $\phi$ 0.2656"  
typ.

typ.  
0.5000

0.5000

0.5000



3x 1/4-20 tap x0.5dp  
typ.

0.2500  
0.5000

{G} Bracket Assembly

Drawn: JHL

Mat'l: al

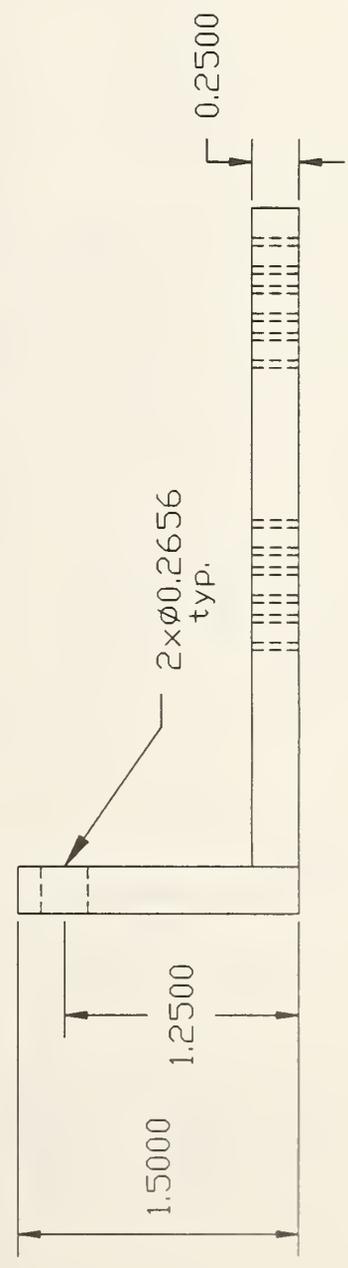
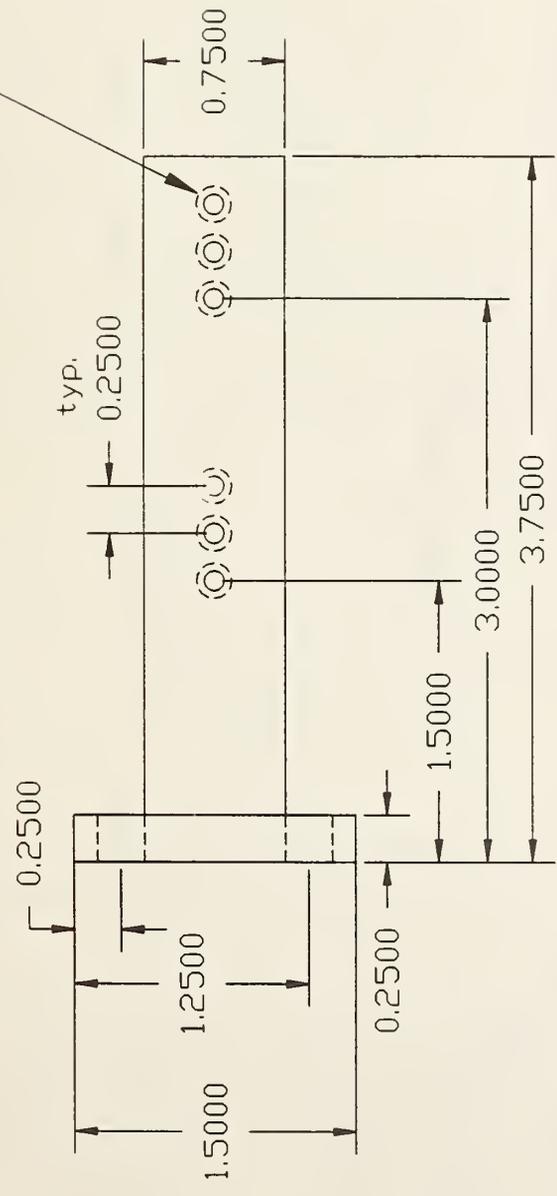
chk: DL

Qty: 1

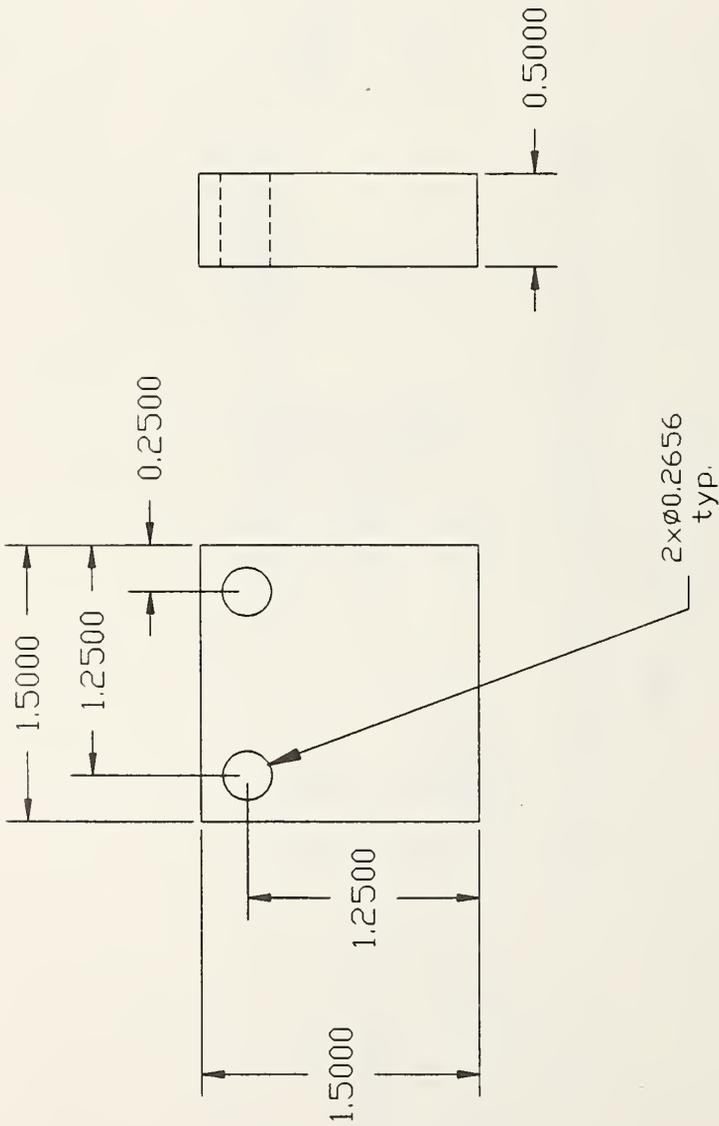
Date: 4 Jun 88 Surface: blk. ano



6x6-32 top  
typ.



}} Substrate Holder			
Drawn: JHL	Mat'l: al		
chk: DL	Qty: 1		
Date: 7 Jun 88	Surface: Ikano		

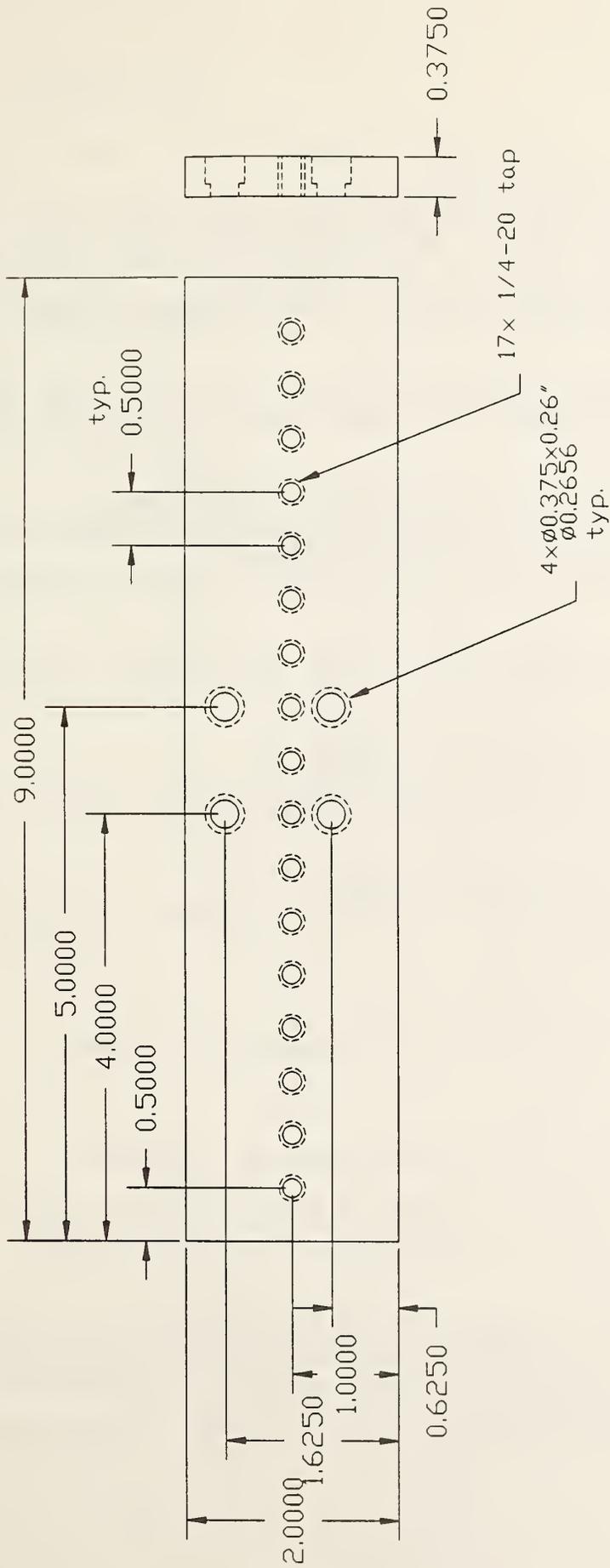


{J} Spacer

Drawn: JHL, Mat'l: al

chk: DL, Qty: 1

Date: 7 Jun 88 Surface: blk.ano



{K} Mounting Plate

Drawn: JHL, Mat'l: al

chk: DL, Qty: 1

Date: 7 Jun 88 Surface: blk.ano.

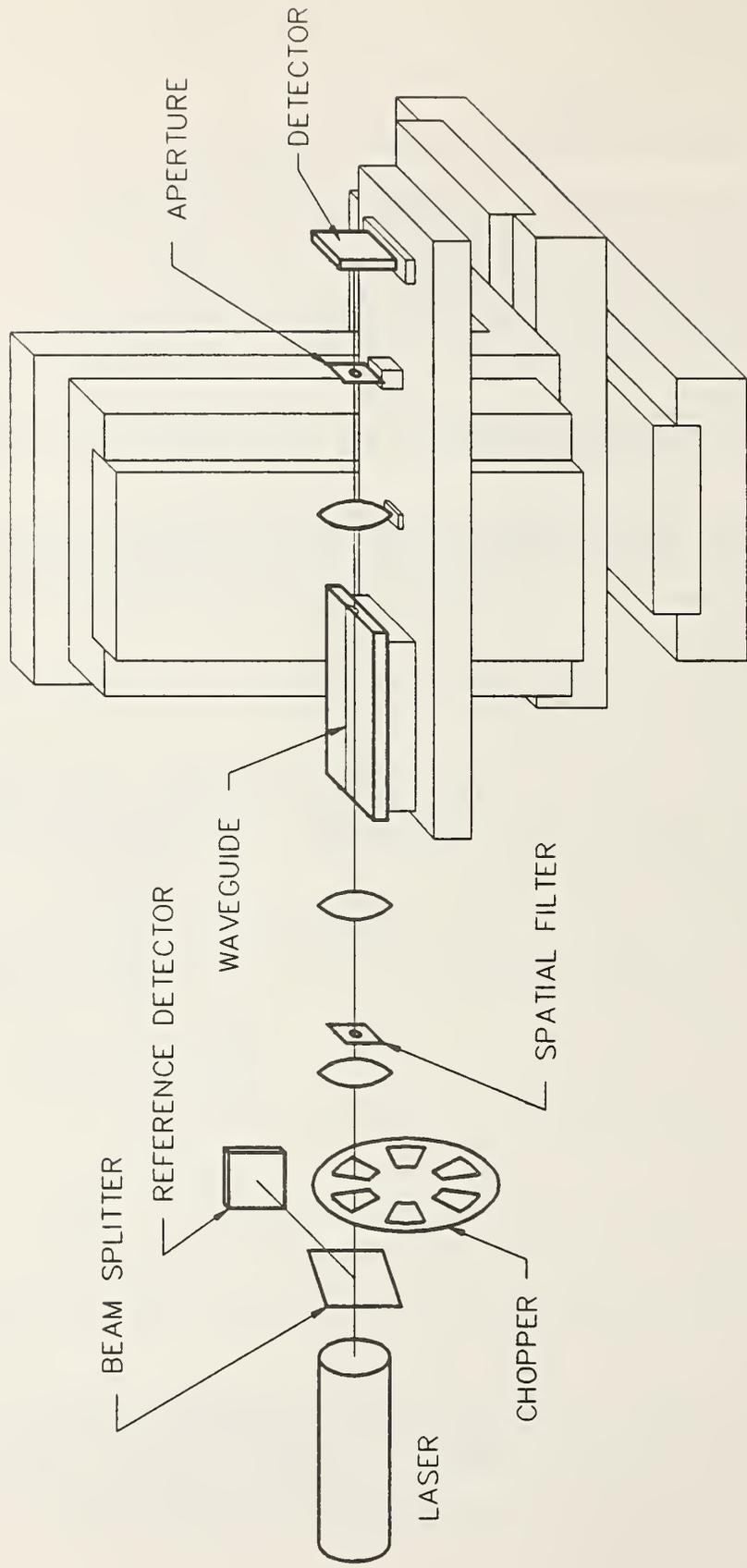
## APPENDIX B

### List of Commercially Available Parts

This list is provided solely for the convenience of the reader who wishes to duplicate this system exactly. The inclusion of a piece of equipment on this list does not imply endorsement or recommendation by the National Bureau of Standards. In many instances alternate pieces of equipment from other manufacturers would perform well.

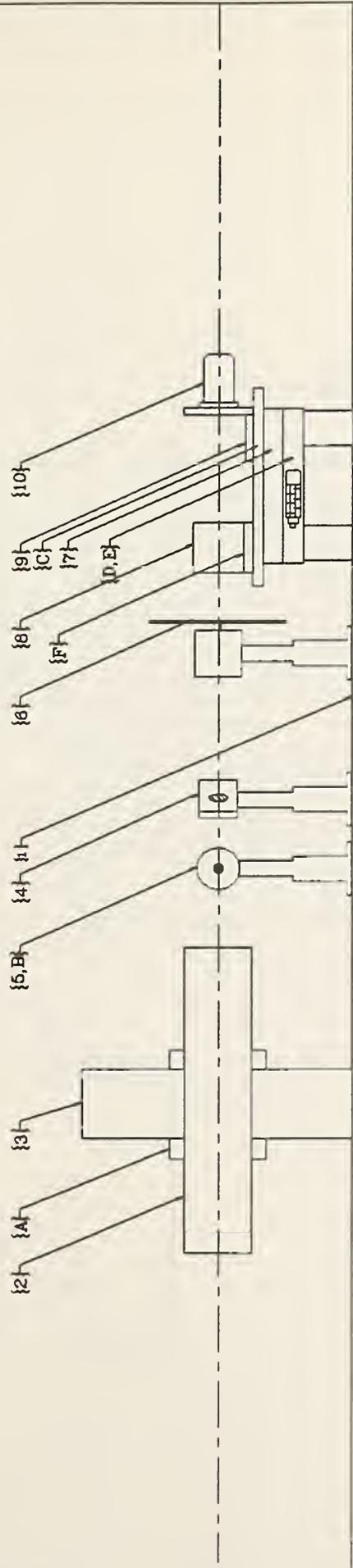
- {1} TMC #74-119-02 Optical Breadboard  
Technical Manufacturing Corp., 15 Centennial Dr., Peabody, MA 01960  
617-532-6330
- {2} Melles Griot #05LHP111 Laser with #05LP340-1 Power Supply  
Melles Griot, 1770 Kettering St., Irvine, CA 92714 714-261-5600
- {3} Newport #806 Mount and #375 Rod/Clamp Assembly  
Newport Corp., 18235 Mt. Baldy Circle, Fountain Valley, CA 92708  
714-63-9811
- {4} Newport #10B20 Beamsplitter, #GM-1B Mount, #VPH-3 Holder, #SP-2 Post,  
#BU-P Base
- {5} Newport #VPH-4 Holder, #SP-3 Post, #BU-P Base  
Centronic #CD-33H Photodiode (2 required)  
Centronic Electro-optics, Inc., 1829 B DeHavilland Dr., Newbury Park,  
CA 91320 805-499-5902
- {6} Stanford Research #SR540 Optical Chopper  
Stanford Research Systems, Inc., 460 California Ave., Palo Alto,  
CA 94306 415-324-3790  
Newport #SP-6 Post, #BU-P Base
- {7} Daedal #4416 Positioning Stage  
Daedal, Inc., P.O. Box G, Harrison, PA 15636 800-245-6903
- {8} Newport #900 Spatial Filter
- {9} Newport #LP-05B Mount with #LPMH-05 Adapter (2 sets needed)
- {10} Edmund Scientific #G30.047, #G30.048, #G30.049 Microscope Objectives  
Edmund Scientific, 101 E. Glouster Pike, Barrington, NJ 08007  
609-547-3488
- {11} Melles Griot Nanomover System and Stage consisting of: 3 #11NCM001  
Nanomover Positioners, #11NCS001 Advanced System Controller, #11NCN001  
Nanomotion Card, 3 #07TSC007 Translation Stages, #07TSB007 Angle  
Bracket, #07TSA007 Z Motion Adapter  
Melles Griot, 1770 Kettering St., Irvine, CA 92714 714-261-5600

- (12)Newport #460-XYZ Stage
- (13)Edmund Scientific #G30.046 Microscope Objective
- (14)Newport #LP-05B Mount with #LPMH-05 Adapter (see (9))
- (15)Newport #ID0.5 Iris and Mount Assembly
- (16)Newport #MPH-1 Post Holder, #MPS-1.5 Post, #BU-P Base  
Centronic #CD-33H Photodiode (see (5))
- (17)EG&G/PAR Model 5209 Lockin Amplifier  
EG&G/PAR, Scientific Instruments Div., P.O. Box 2565, Princeton,  
NJ 08543 609-452-2111
- (18)Bausch and Lomb SVB-73 Microscope, #31-26-40-73  
Bausch and Lomb, Inc., Box 450, Rochester, NY 14692 716-338-6086



COMPUTER CONTROLLED XYZ STAGE

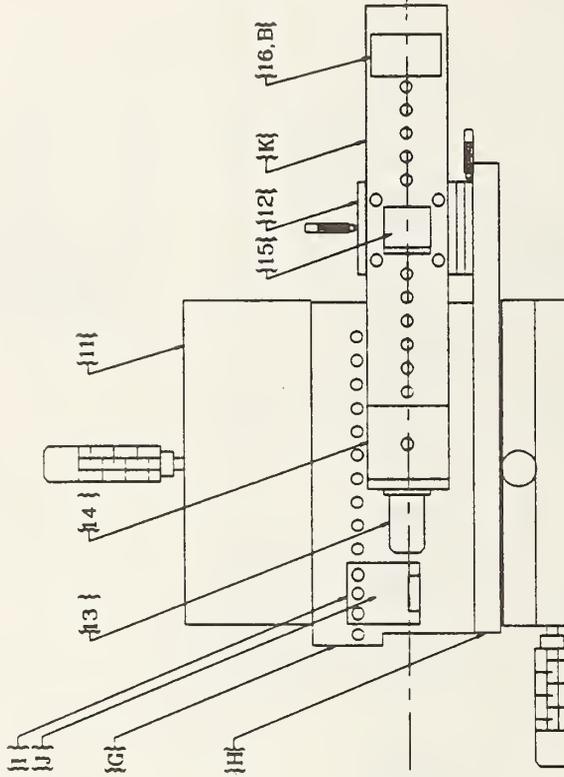
Figure 1. Diagram of the CEM System.



- 1 Optical Breadboard
- 2 Laser
- 3 Mount
- 4 Beam Splitter
- 5 Reference Detector
- 6 Chopper
- 7 One Axis Stage
- 8 Spatial Filter
- 9 Objective Holder
- 10 Objective

- A Spacer
- B Detector Case
- C Mounting Plate
- D Optical Table
- E Optical Table
- F Spacer

Figure 2. Source and entrance optics.



- G Bracket Assembly
- H Bracket Assembly
- I Substrate Holder
- J Spacer
- K Mounting Plate

- 11 Computer Controlled Stage (3 axis)
- 12 Manual Stage (3 axis)
- 13 Microscope Objective
- 14 Objective Holder
- 15 Aperture
- 16 Detector

Figure 3. Stage and exit optics.

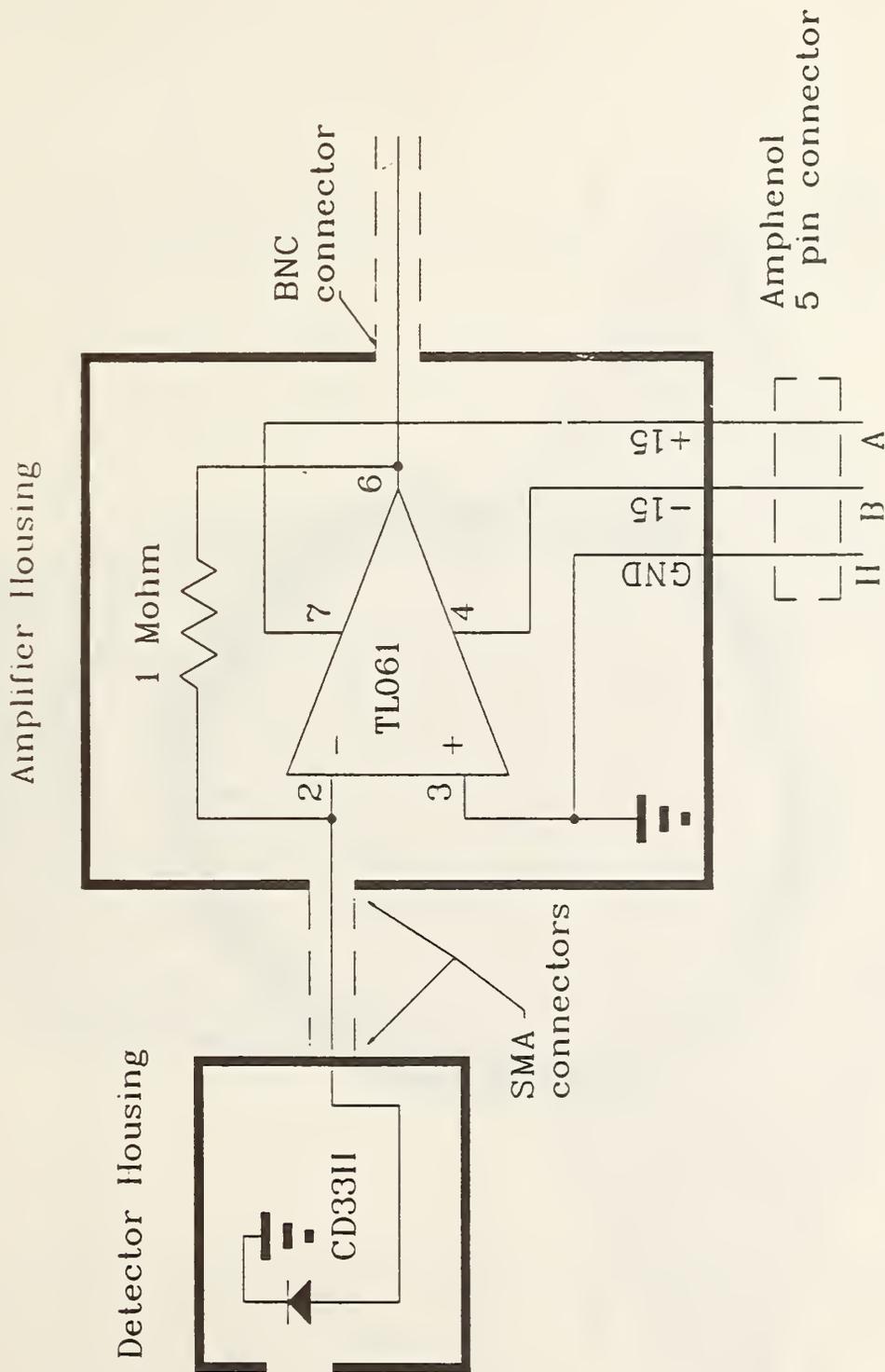


Figure 4. Detector amplifier schematic.

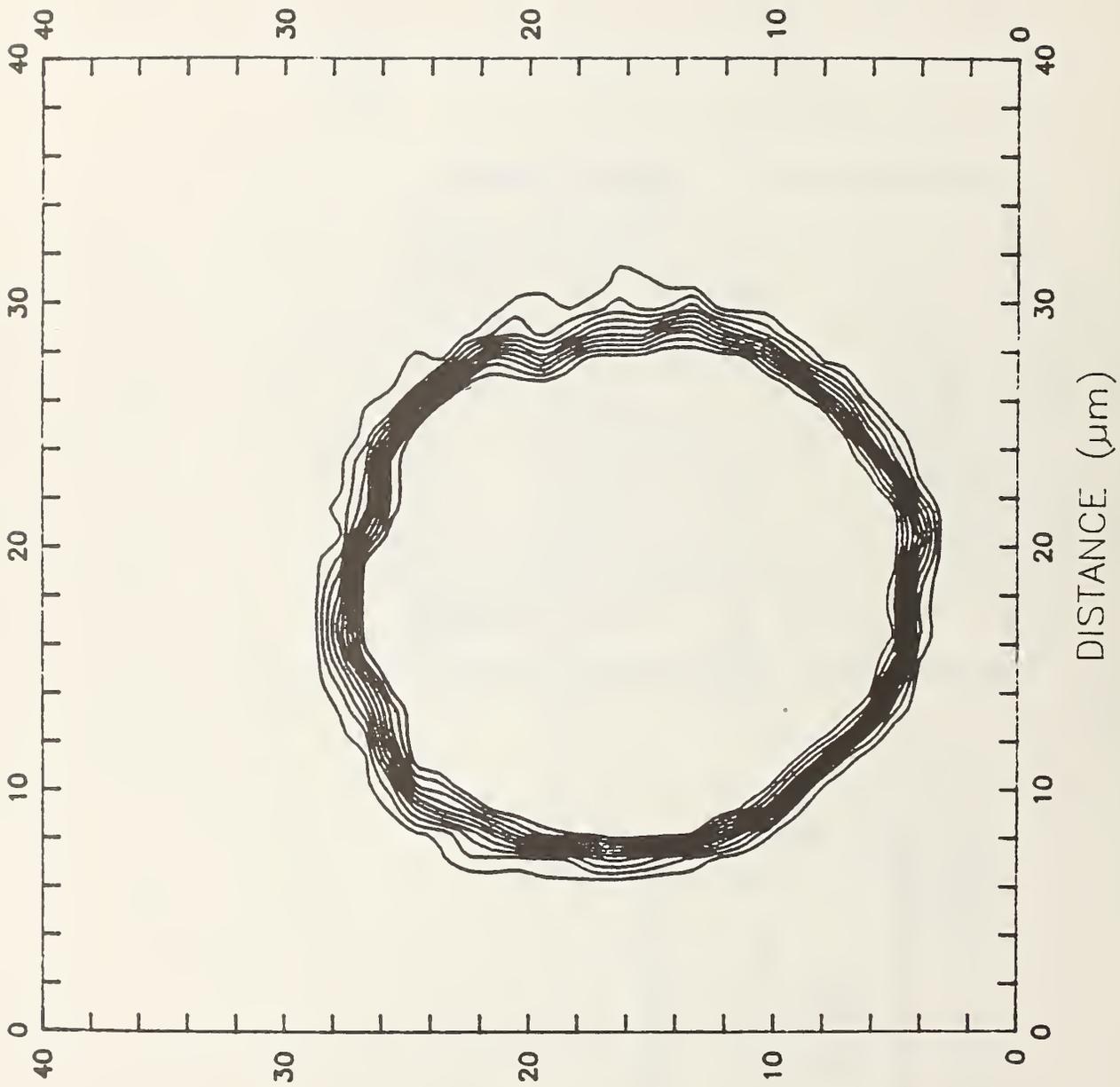


Figure 5. Data from 25  $\mu\text{m}$  pinhole.

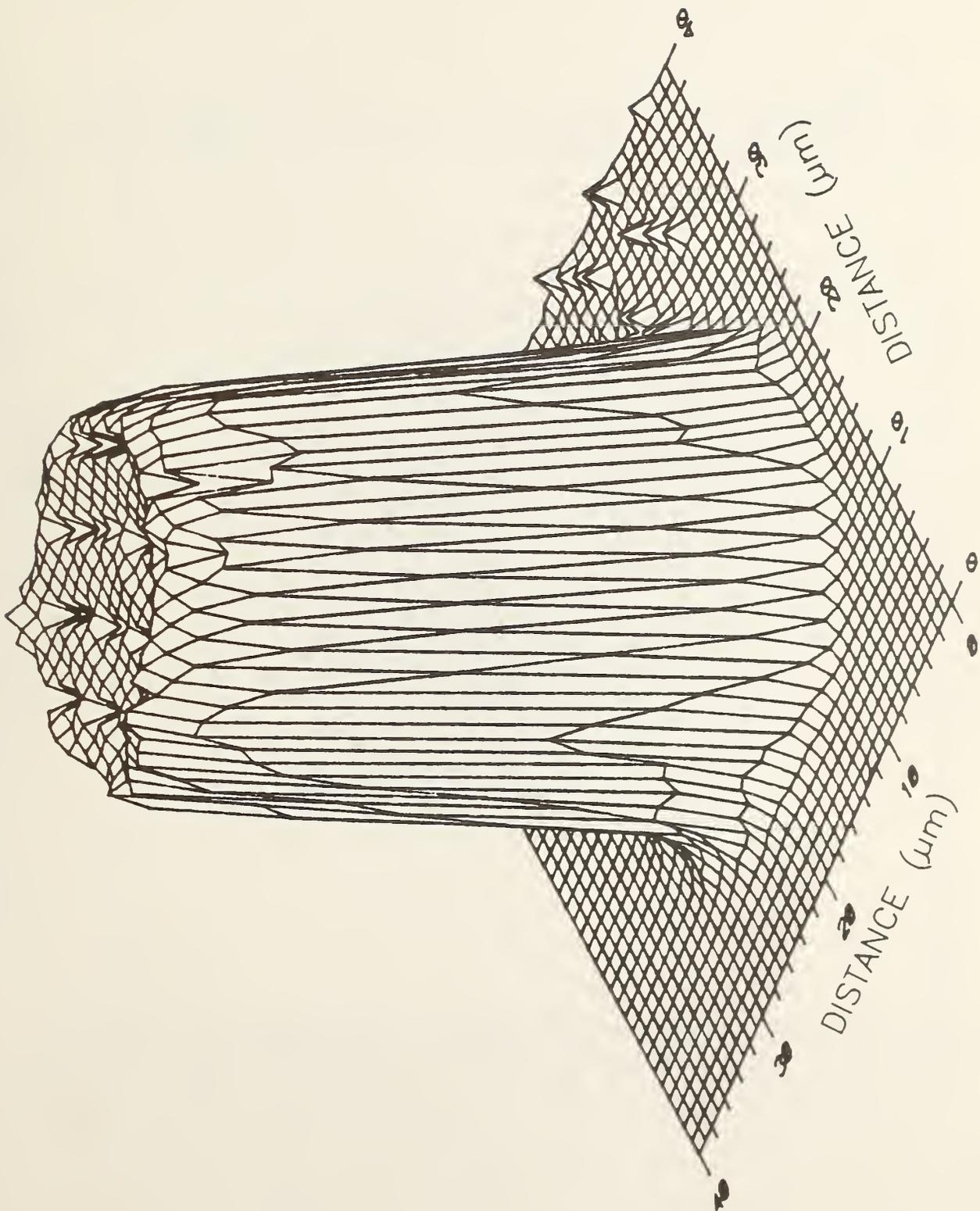


Figure 6. Data from 25 μm pinhole.

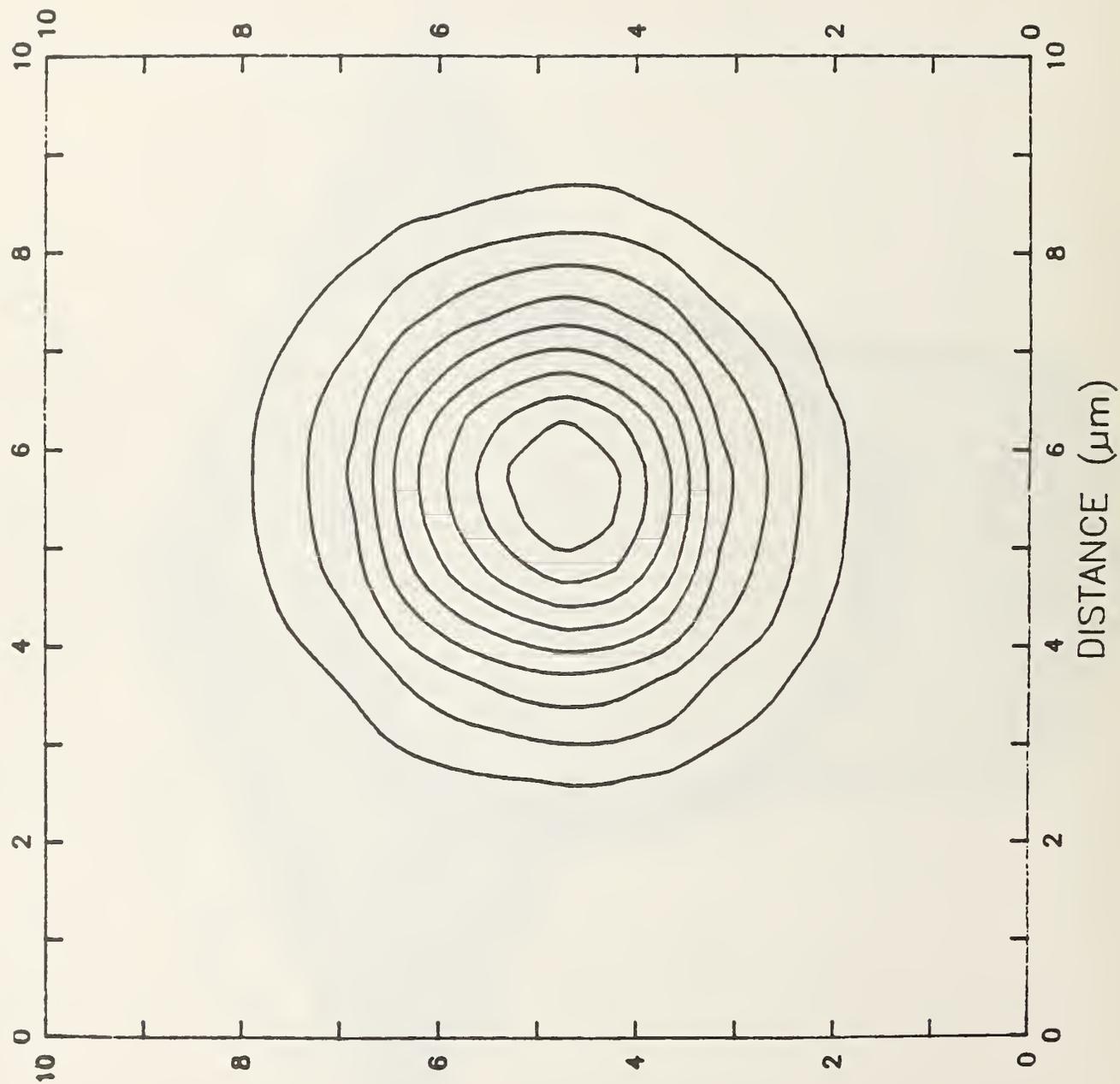


Figure 7. Data from single mode fiber, out of focus.

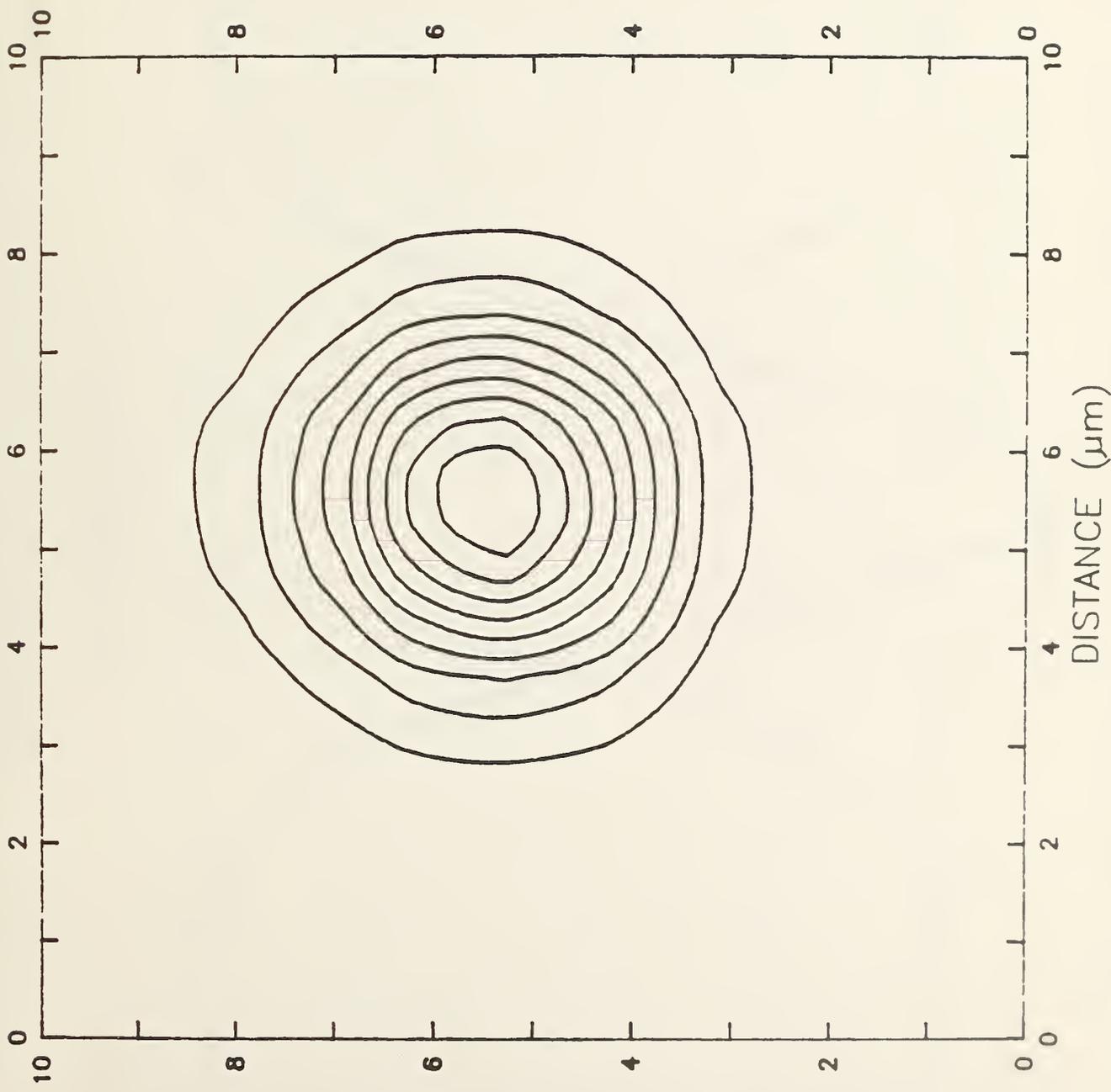


Figure 8. Data from single mode fiber, in focus.

— Expt  
— Gaussian

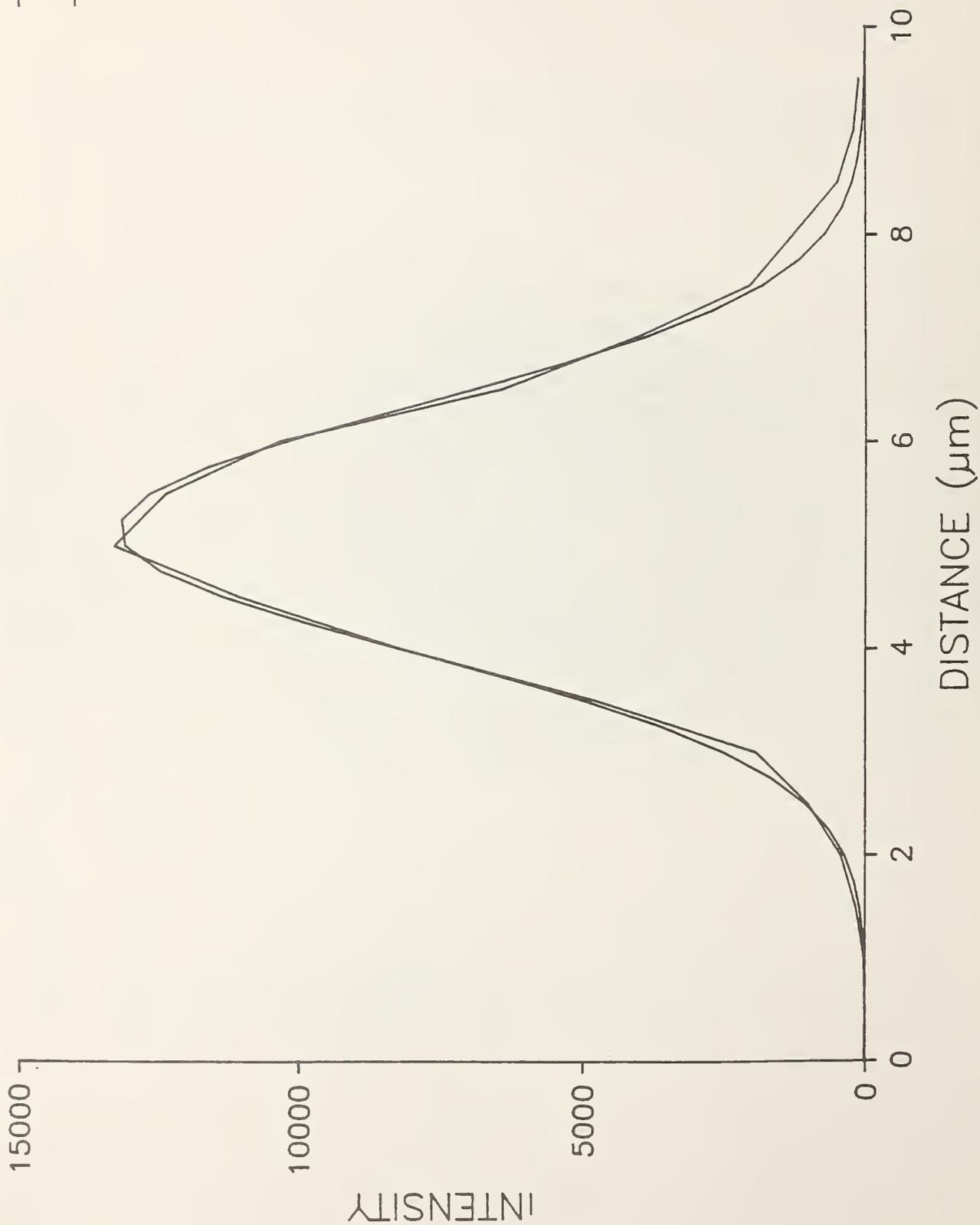


Figure 9. Vertical cross section of data from single mode fiber, with Gaussian fit.

— Expt  
— Gaussian

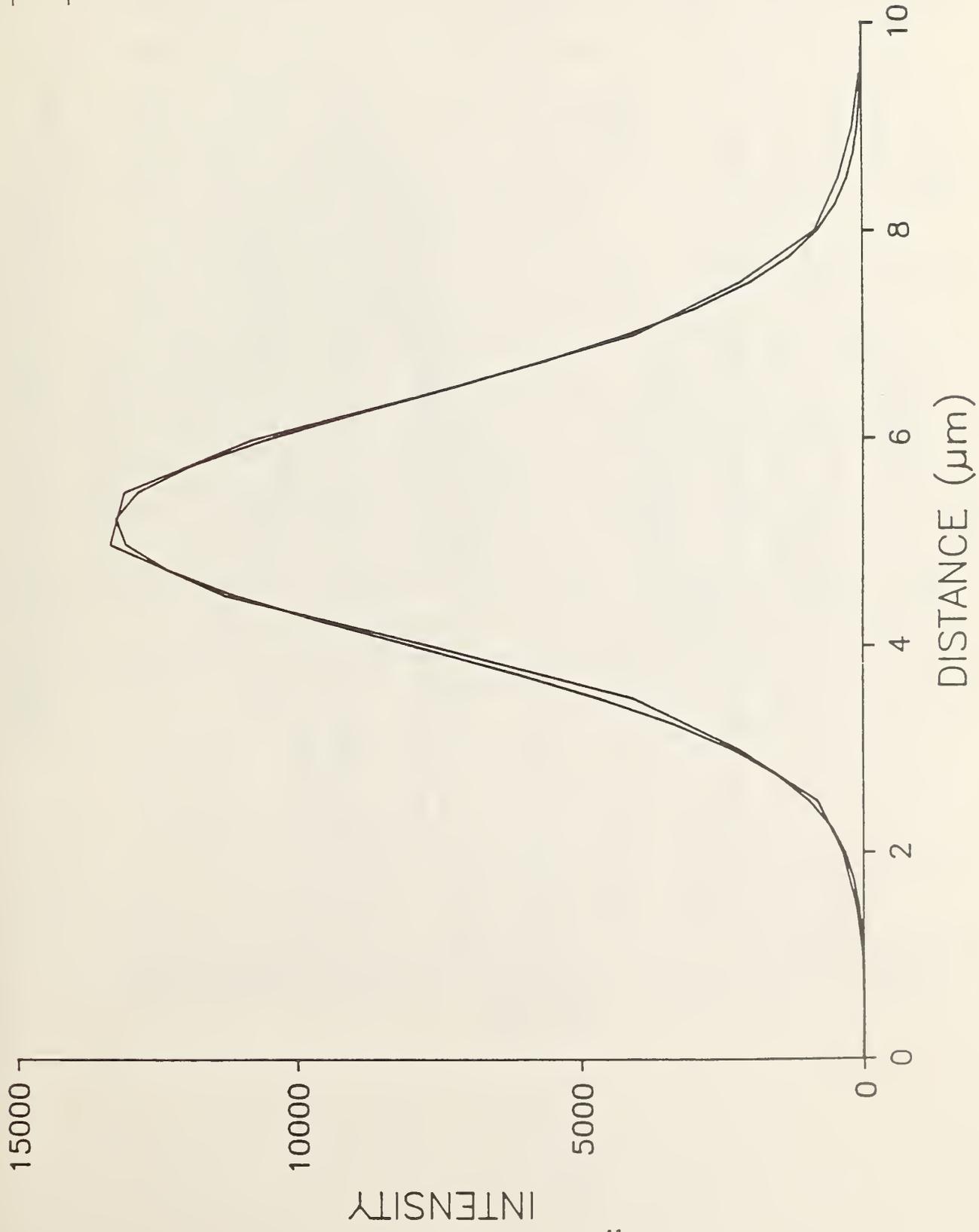


Figure 10. Horizontal cross section of data from single mode fiber, with Gaussian fit.

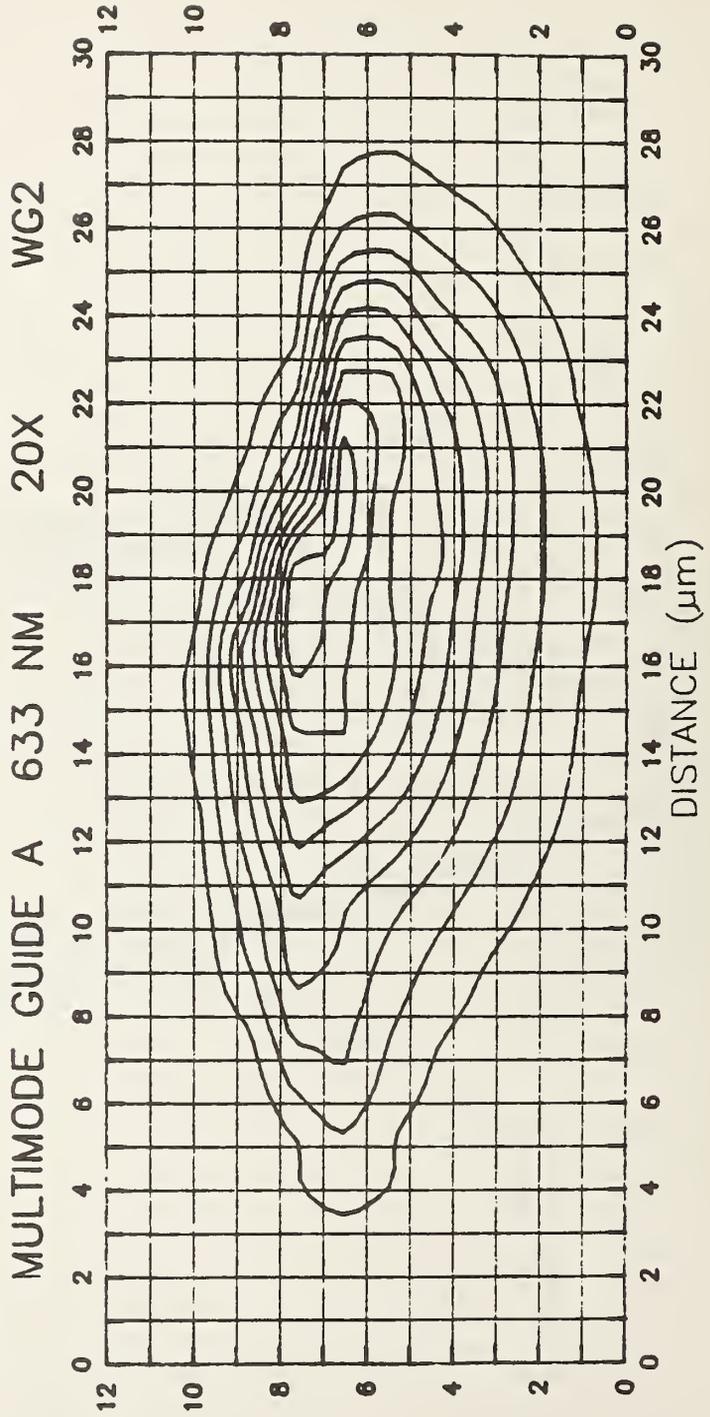
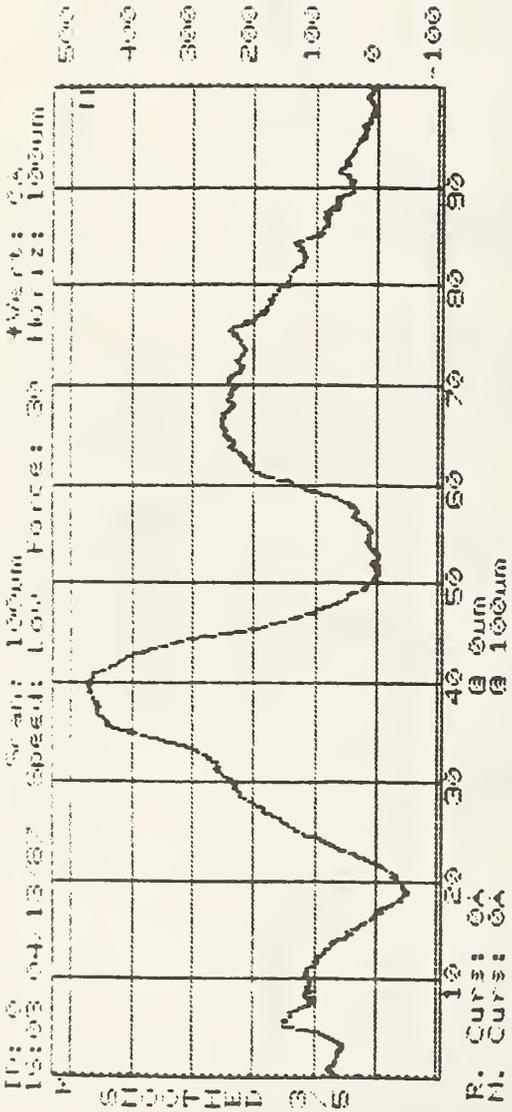
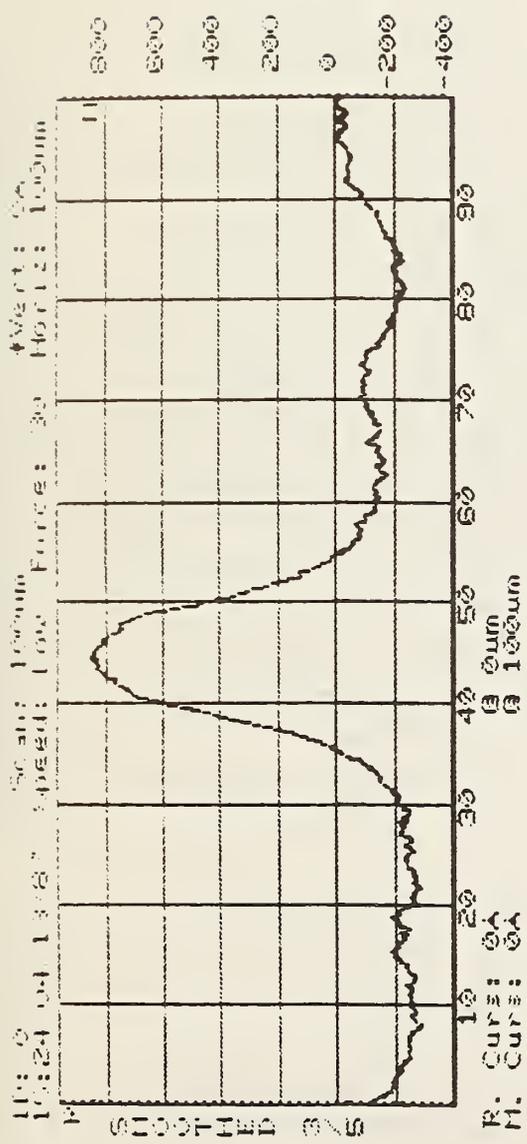


Figure 11. Mechanical surface profile (top) and corresponding mode intensity profile (bottom) of optical waveguide.



MULTIMODE GUIDE A 633 NM 20X WGBACKA1

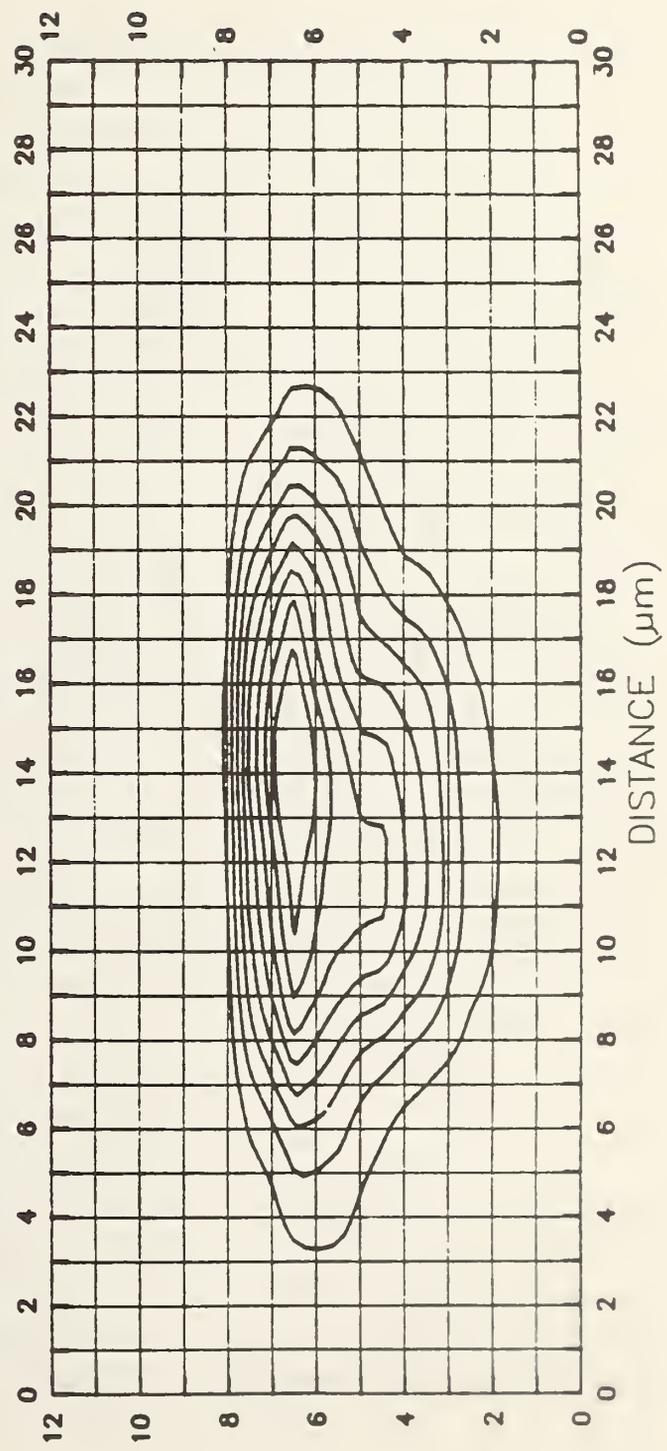
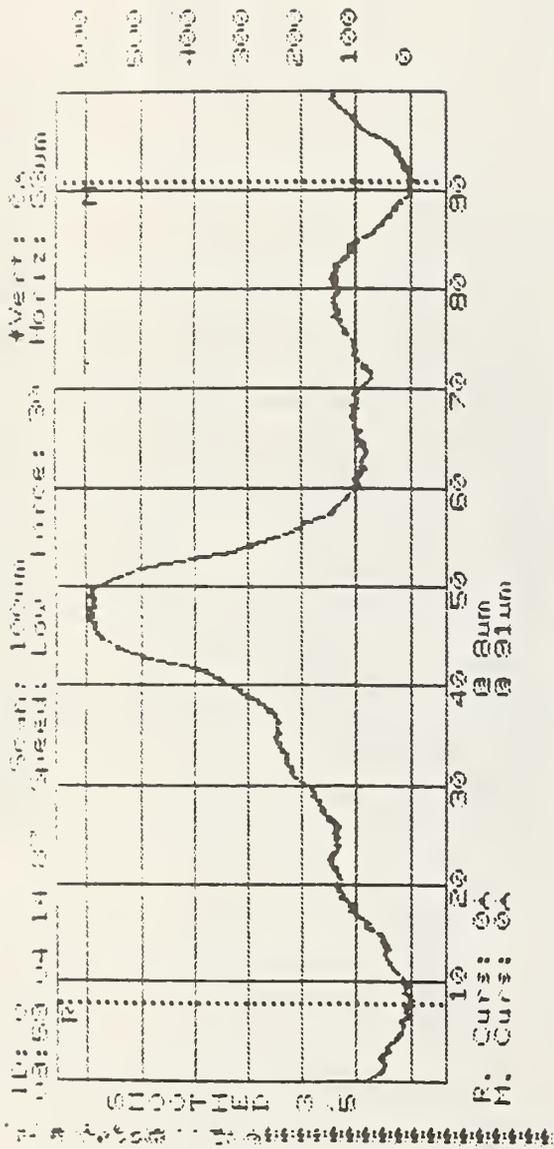


Figure 12. Mechanical surface profile (top) and corresponding mode intensity profile (bottom) of optical waveguide.



MULTIMODE GUIDE B 633 NM 20X WGB3

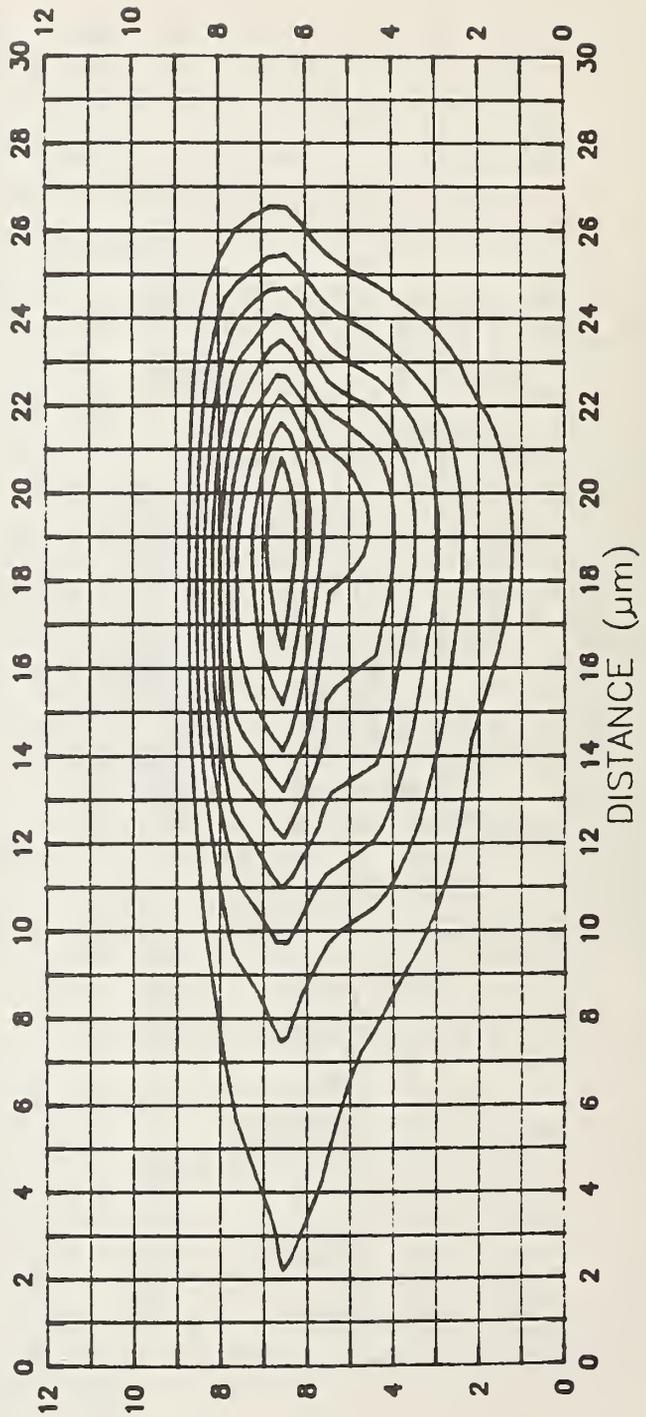
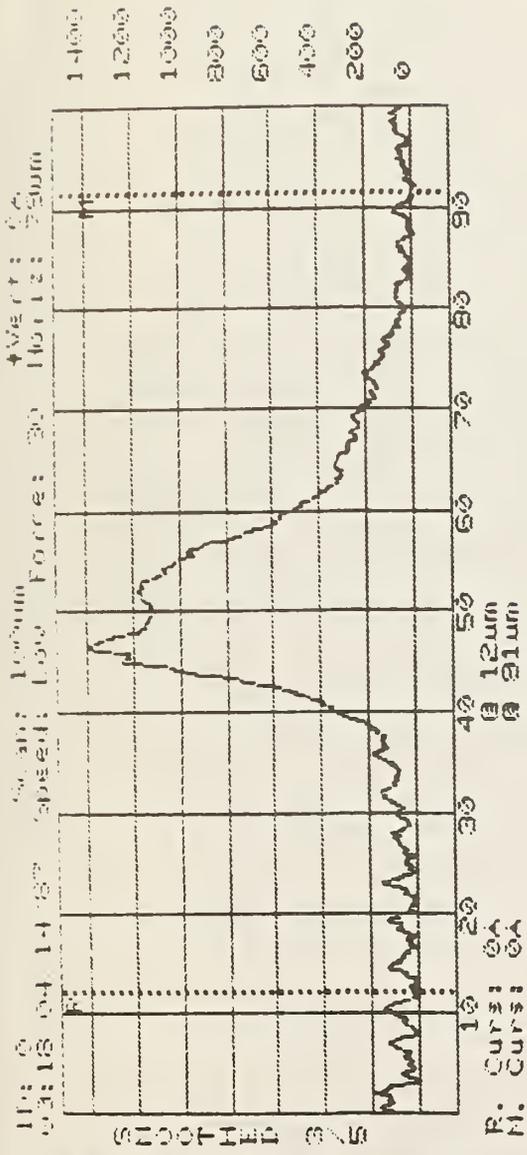


Figure 13. Mechanical surface profile (top) and corresponding mode intensity profile (bottom) of optical waveguide.



MULTIMODE GUIDE A 633 NM 20X WGBACKB1

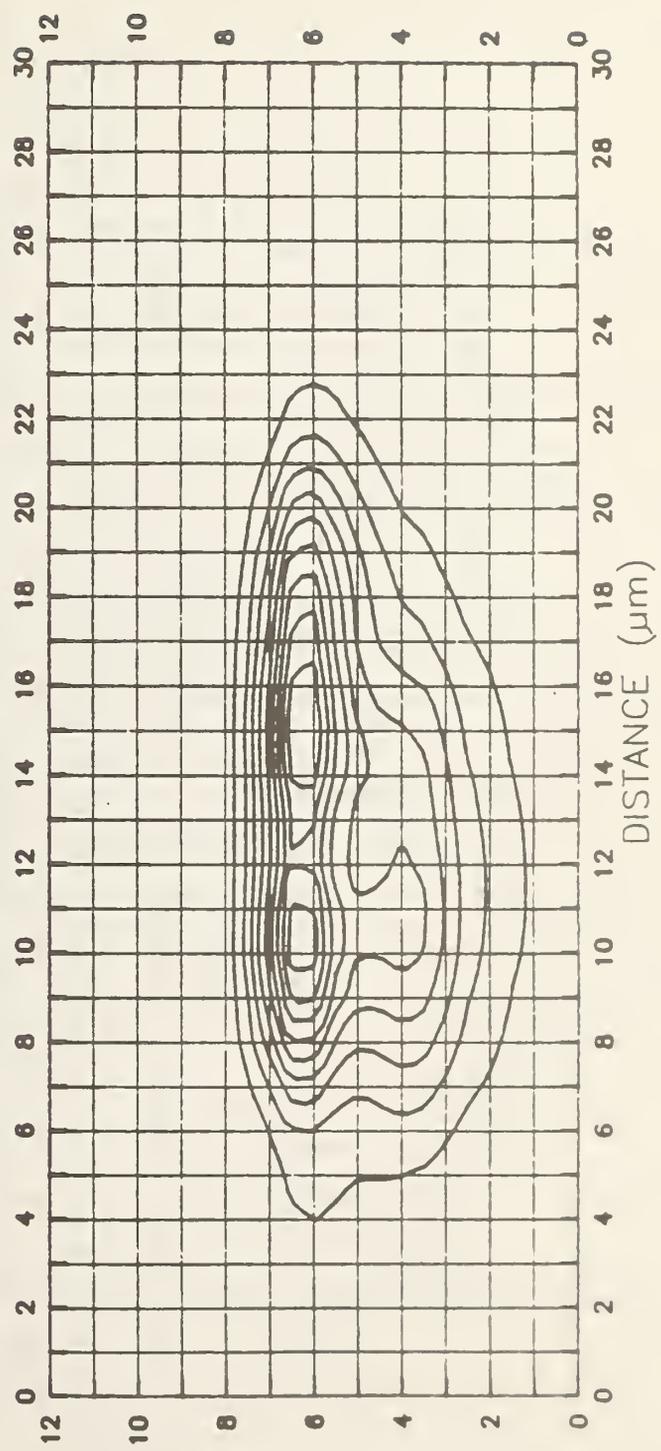


Figure 14. Mechanical surface profile (top) and corresponding mode intensity profile (bottom) of optical waveguide.



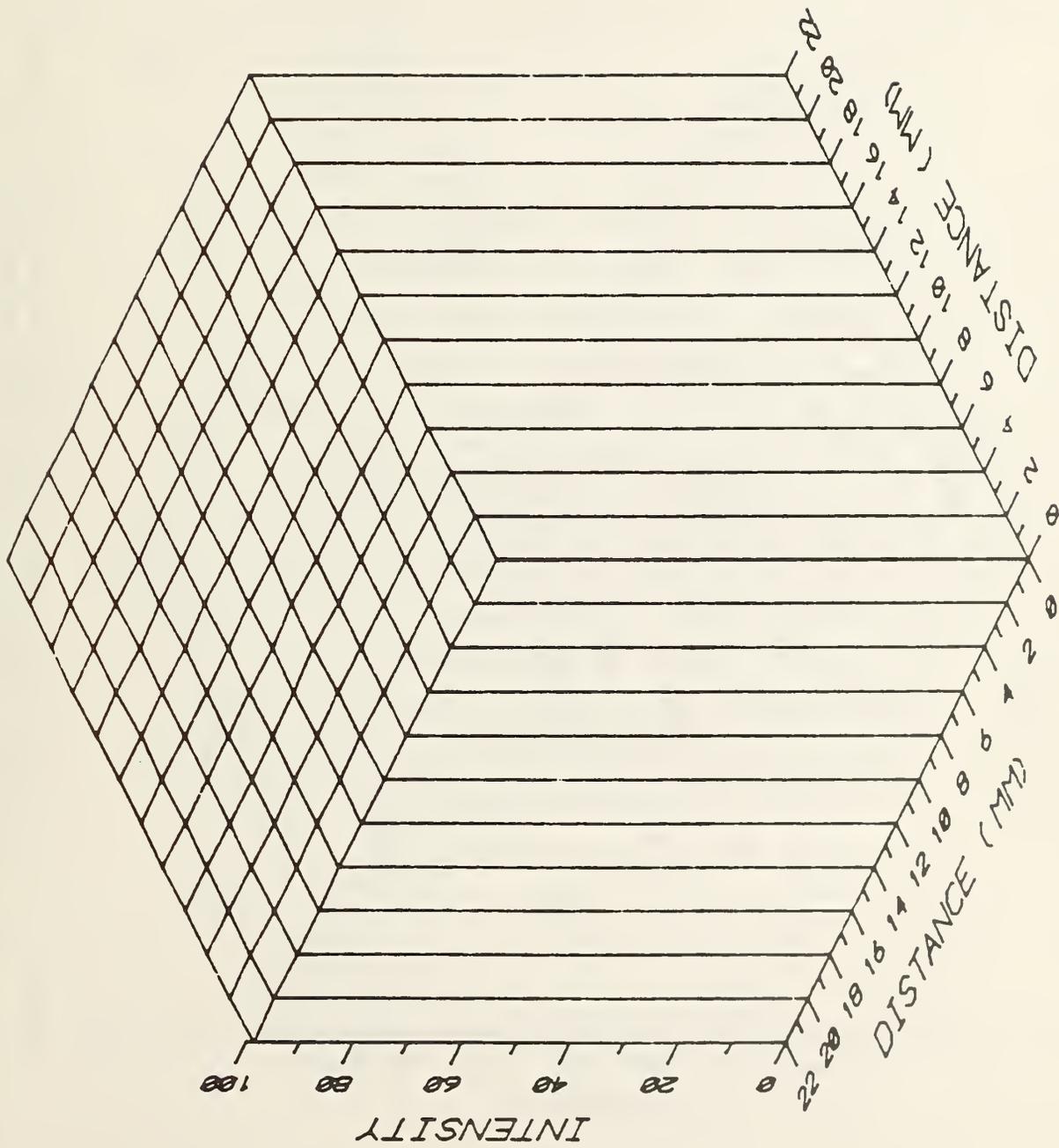


Figure 16. Measurement of intensity of light from a fiber, as fiber end position is changed. Source is He-Ne laser.

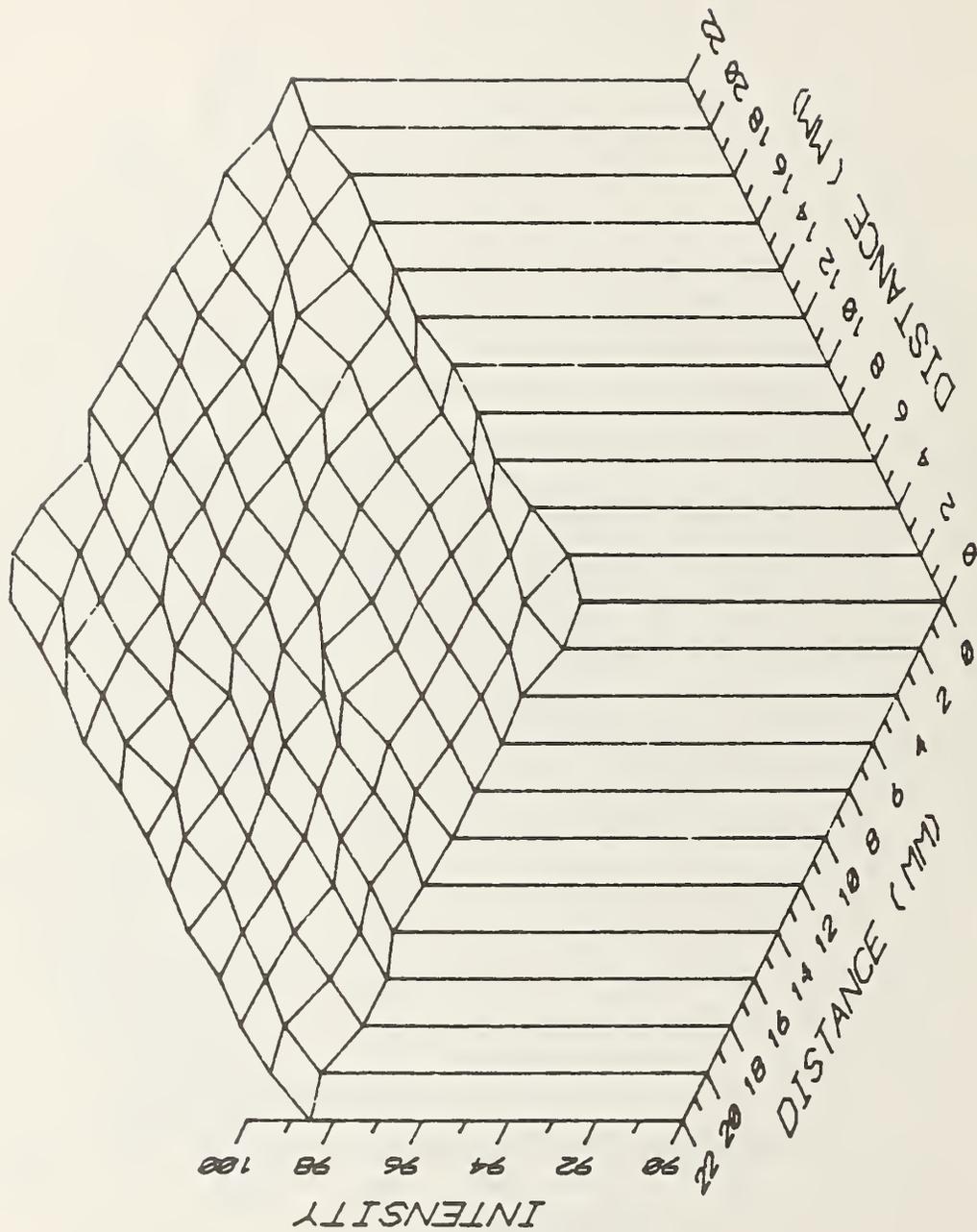


Figure 17. Measurement of intensity of light from a fiber, as fiber end position is changed. Source is He-Ne laser.

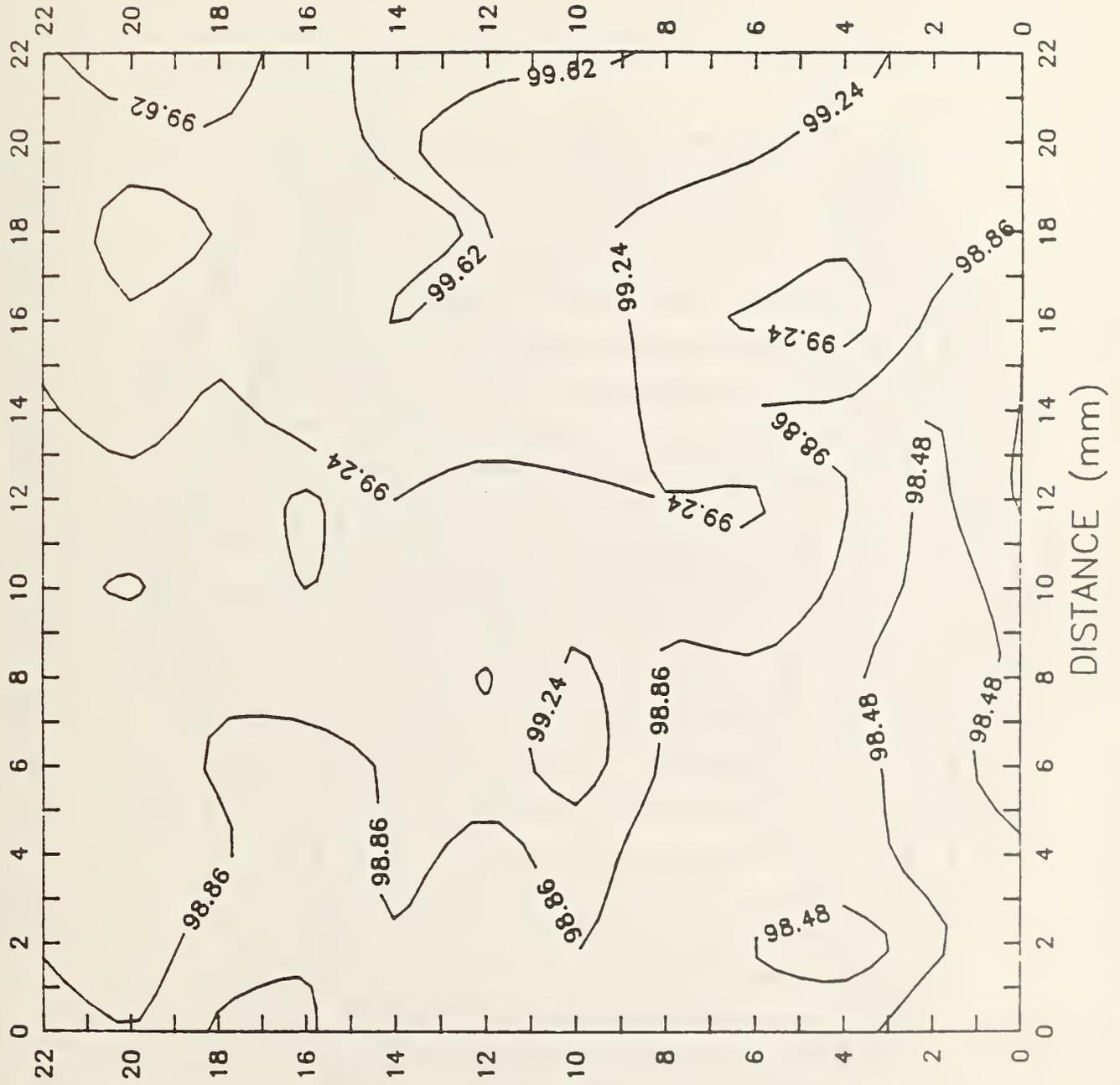


Figure 18. Measurement of intensity of light from a fiber, as fiber end position is changed. Source is He-Ne laser.

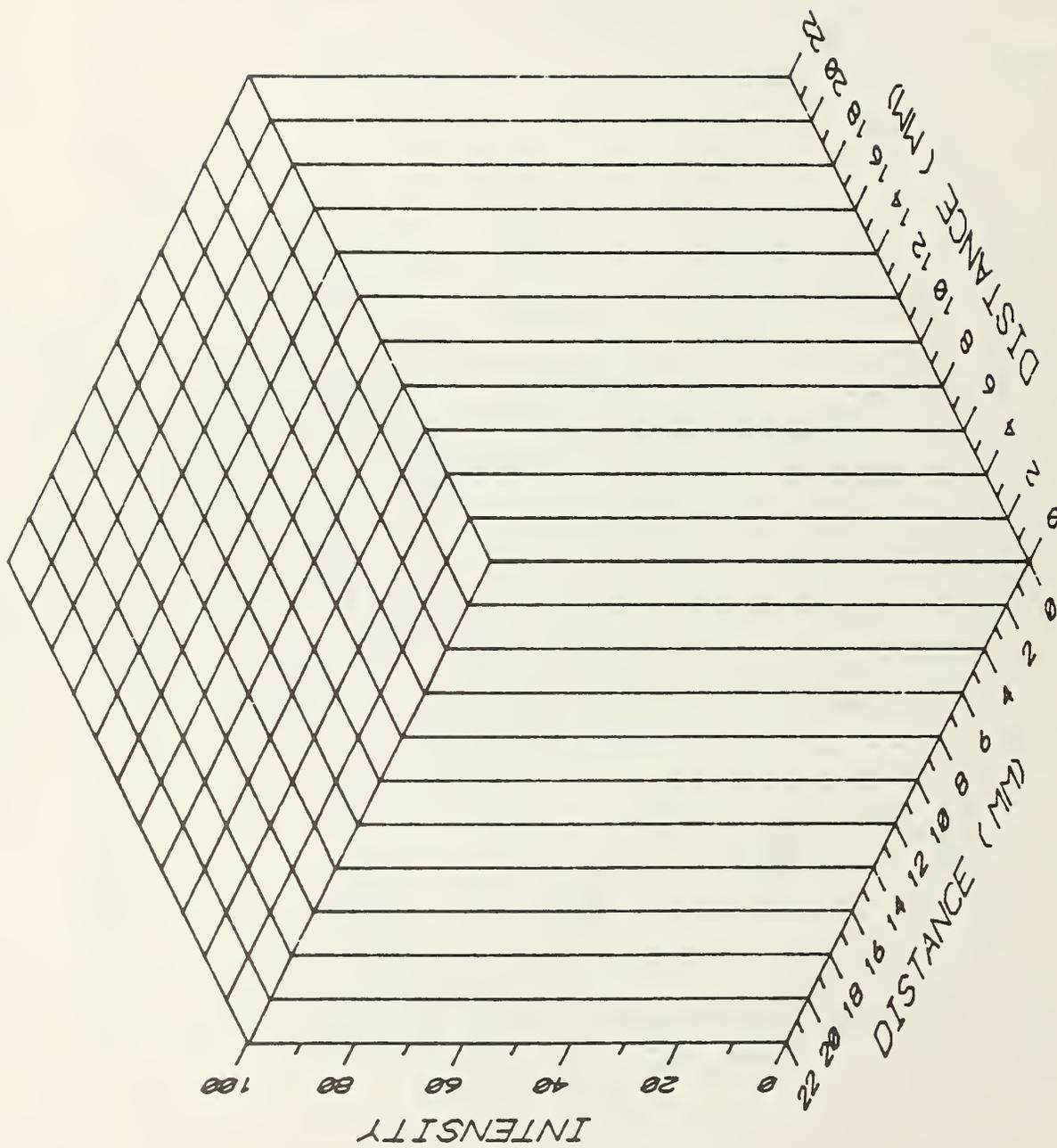


Figure 19. Measurement of intensity of light from a fiber, as fiber end position is changed. Source is a laser diode operating at 750 nm.

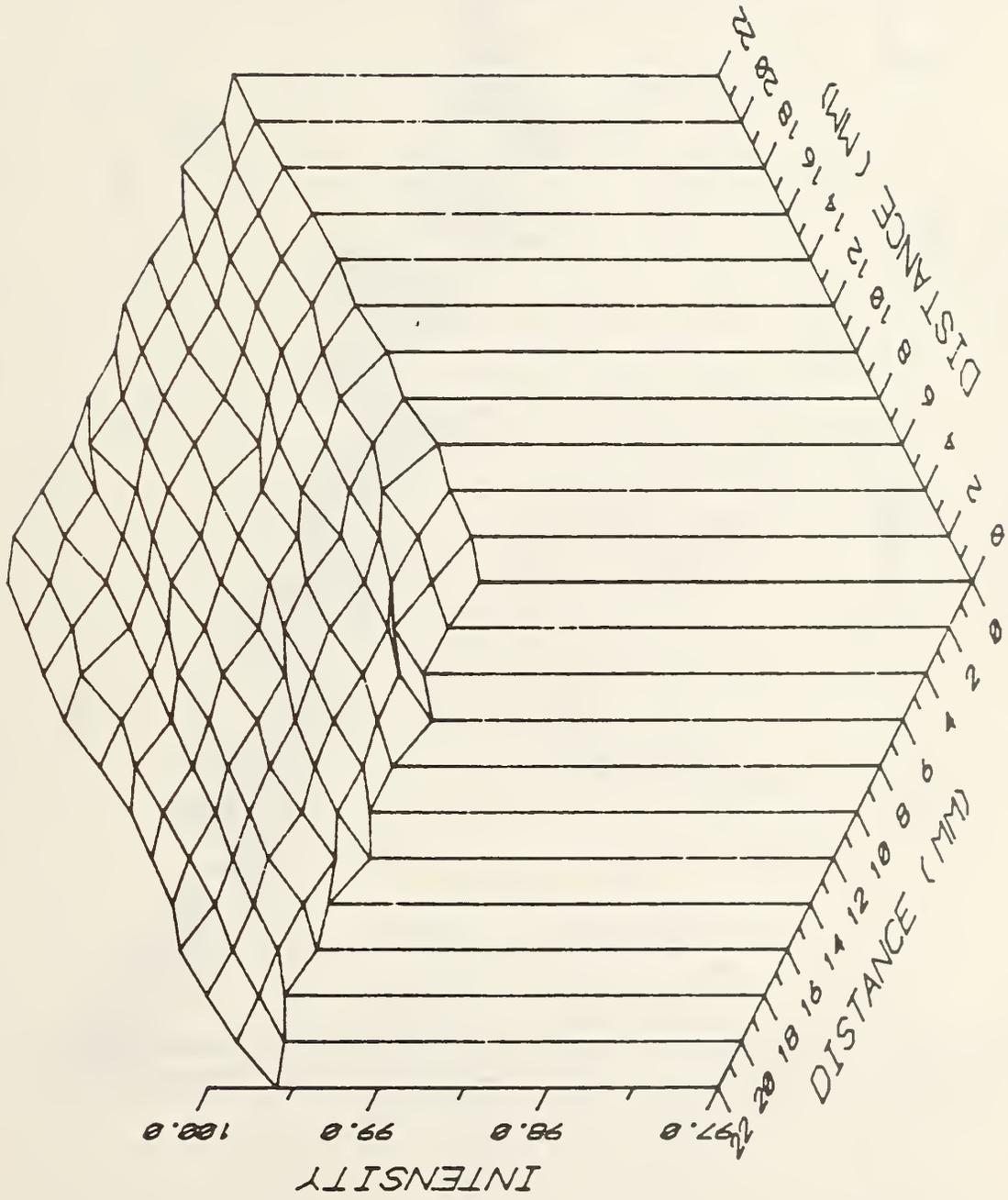


Figure 20. Measurement of intensity of light from a fiber, as fiber end position is changed. Source is a laser diode operating at 750 nm.

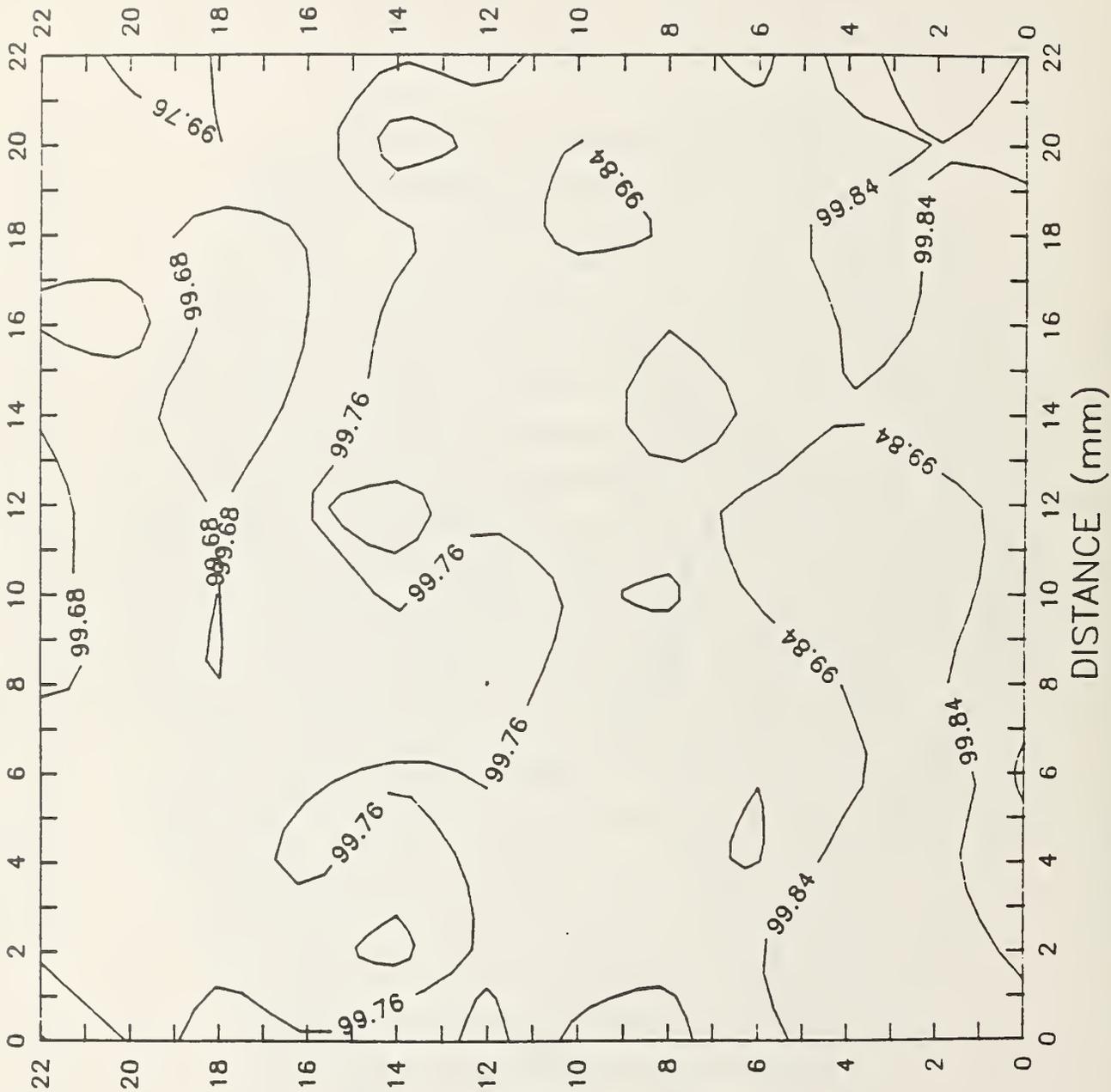


Figure 21. Measurement of intensity of light from a fiber, as fiber end position is changed. Source is a laser diode operating at 750 nm.

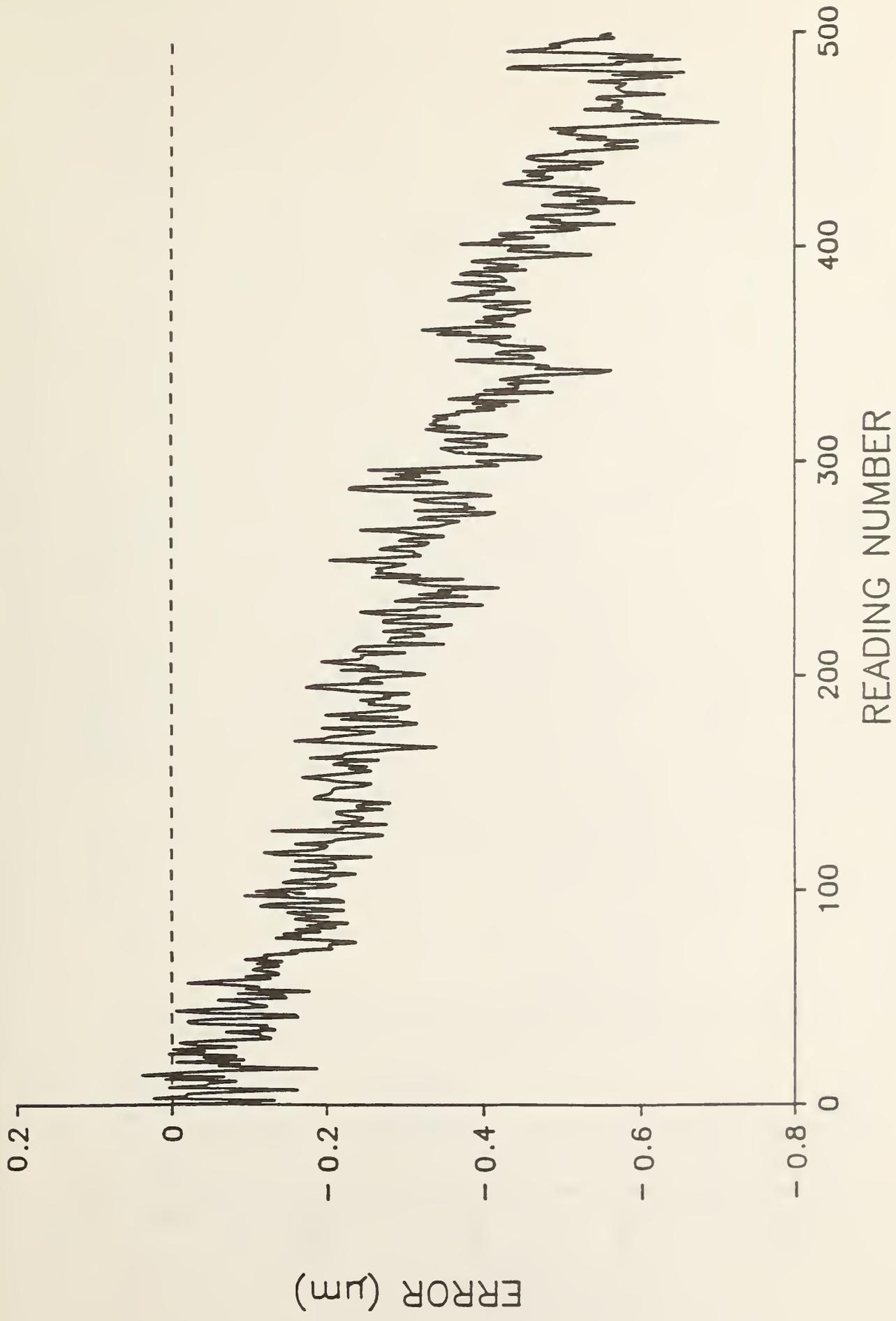


Figure 22. Data from laser interferometer showing stage position, stage not moving.

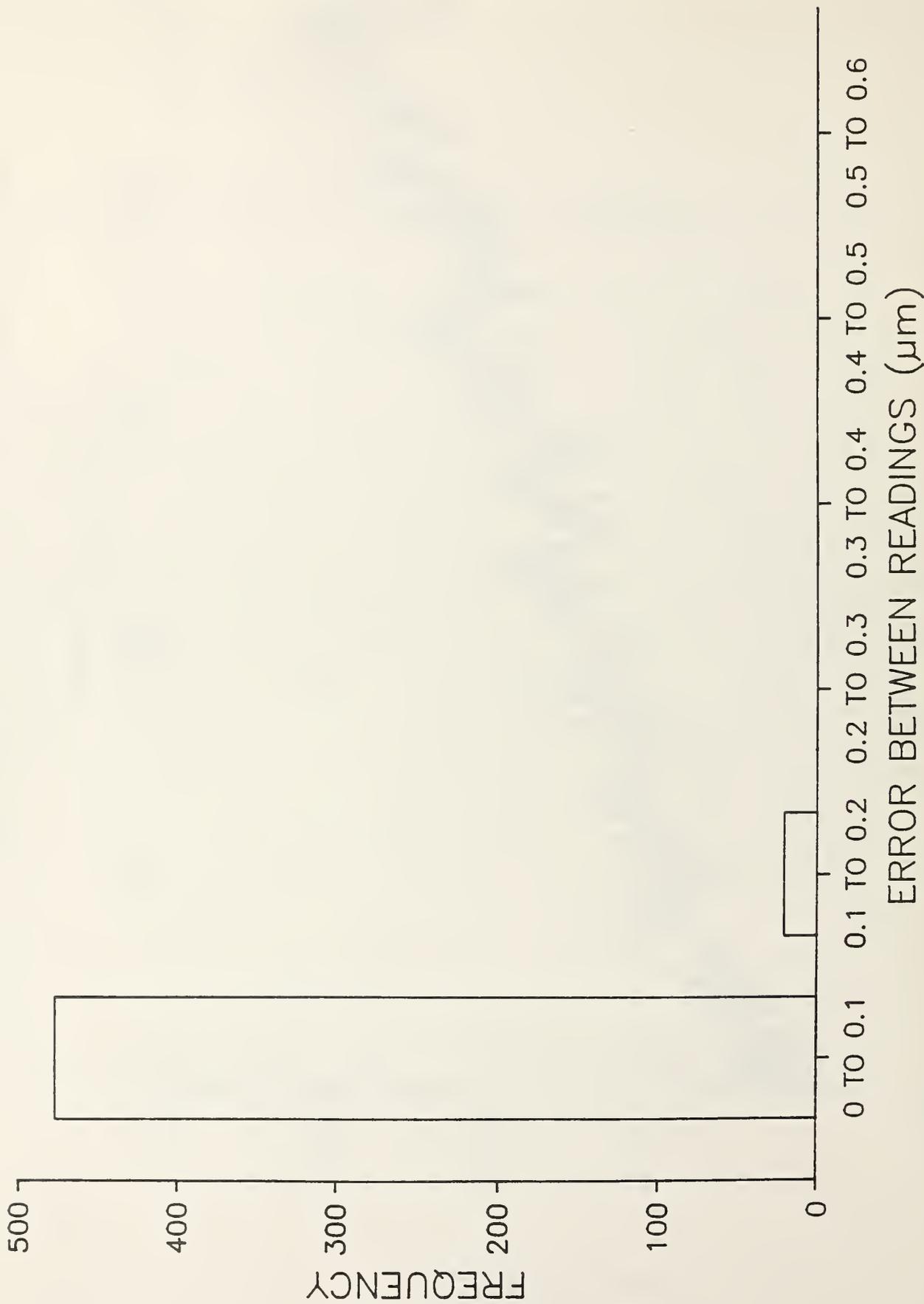


Figure 23. Data from laser interferometer showing stage position, stage not moving.

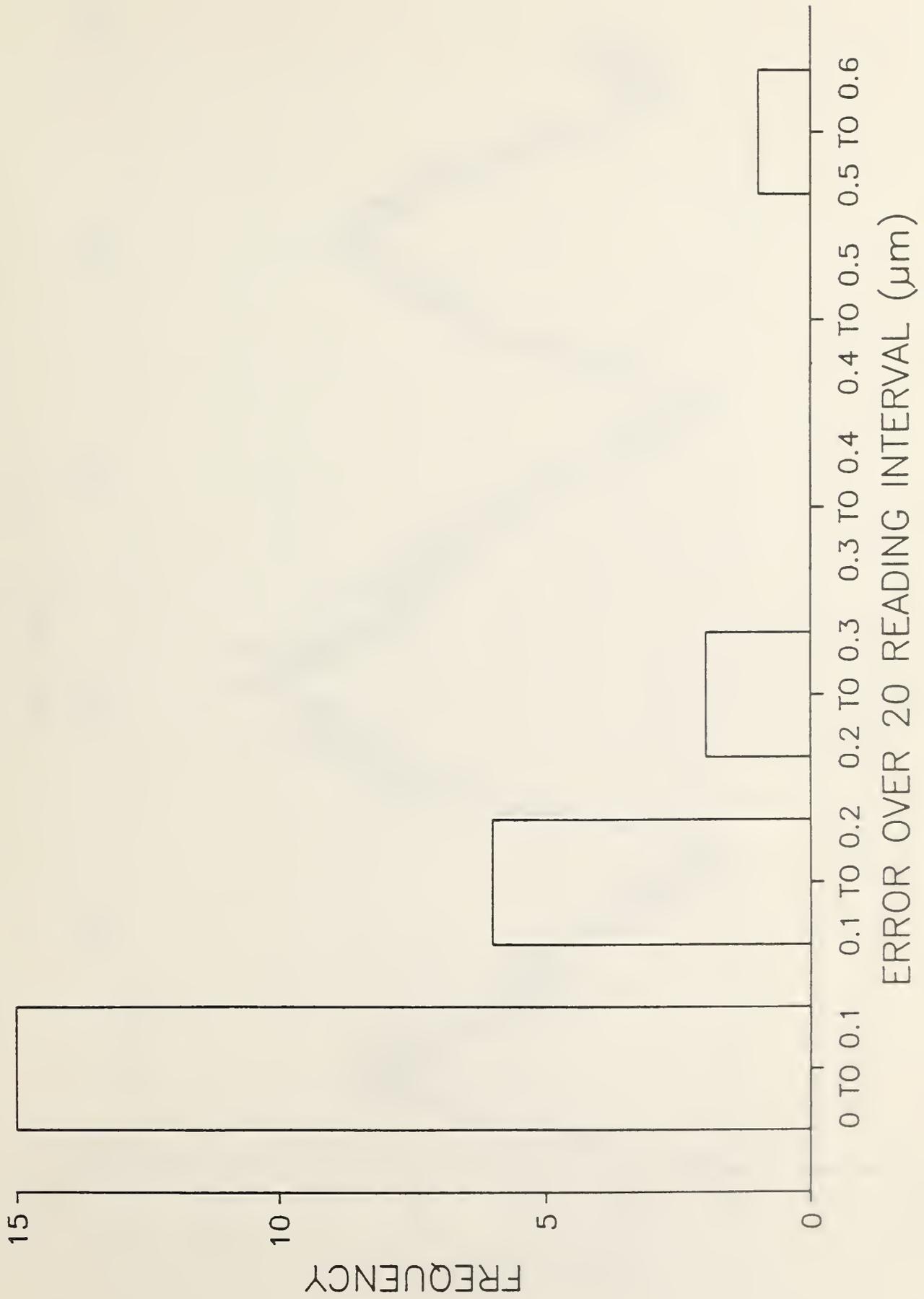


Figure 24. Data from laser interferometer showing stage position, stage not moving.

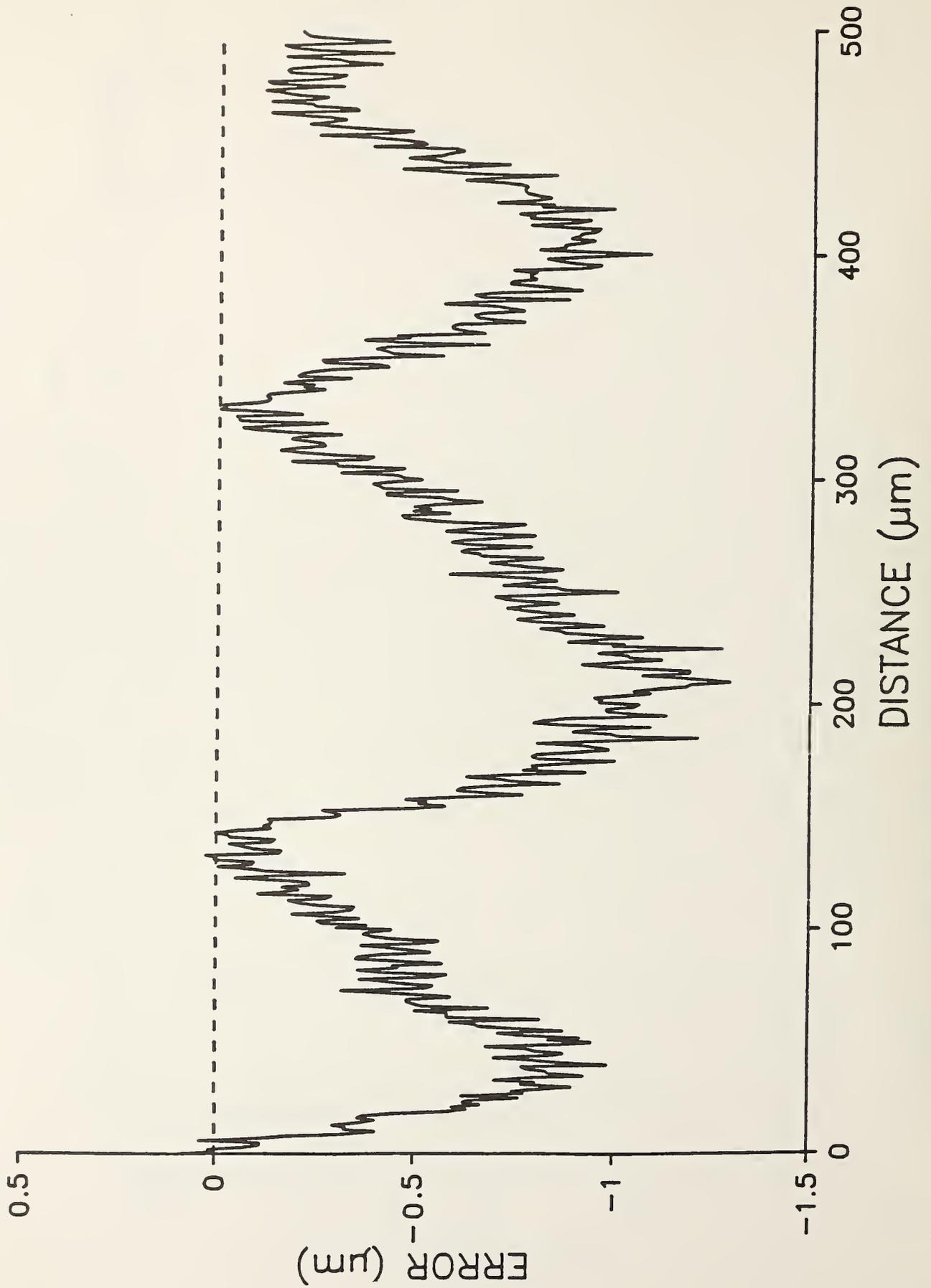


Figure 25. Data from laser interferometer showing error in stage position.

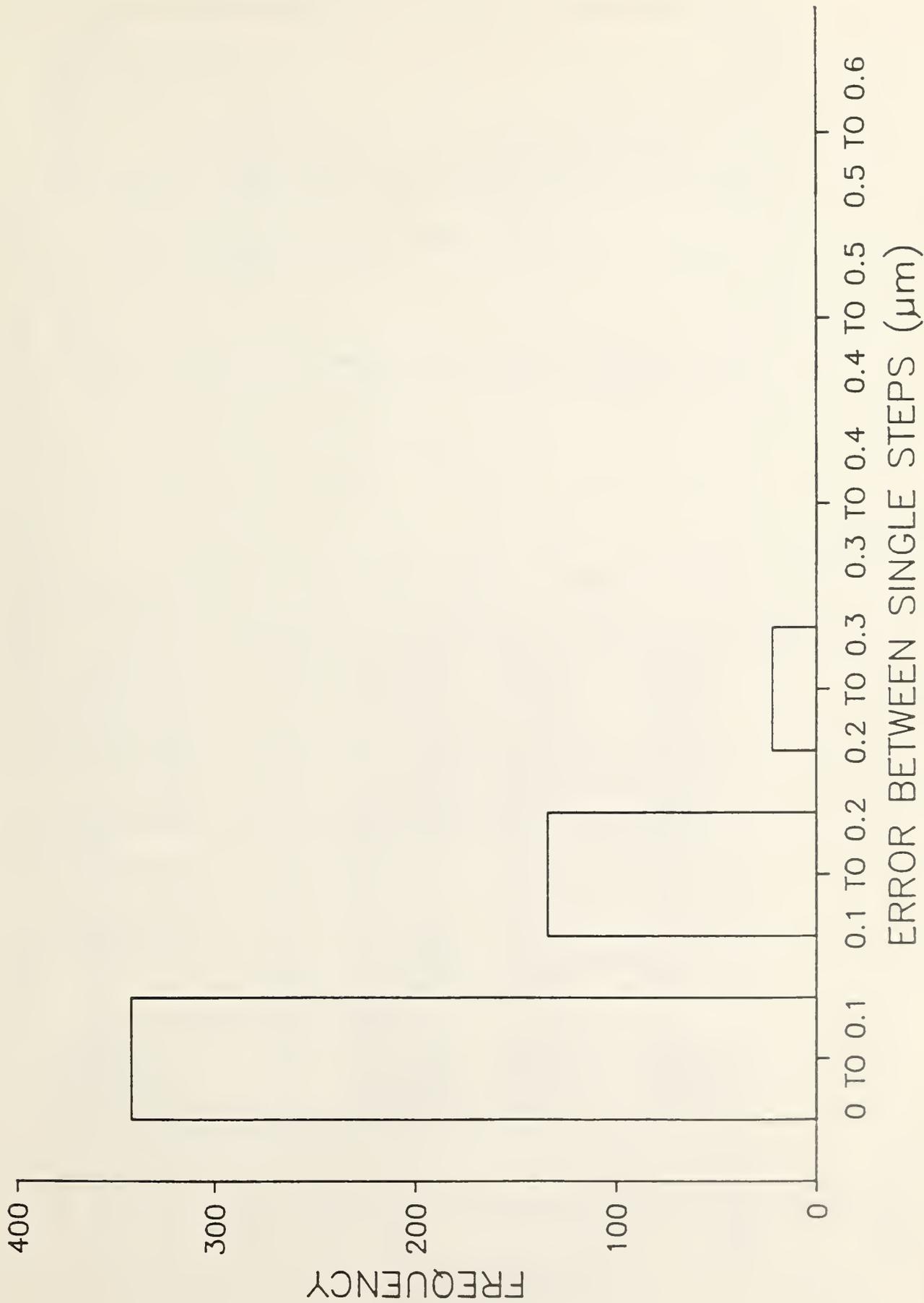


Figure 26. Data from laser interferometer showing error in stage position.

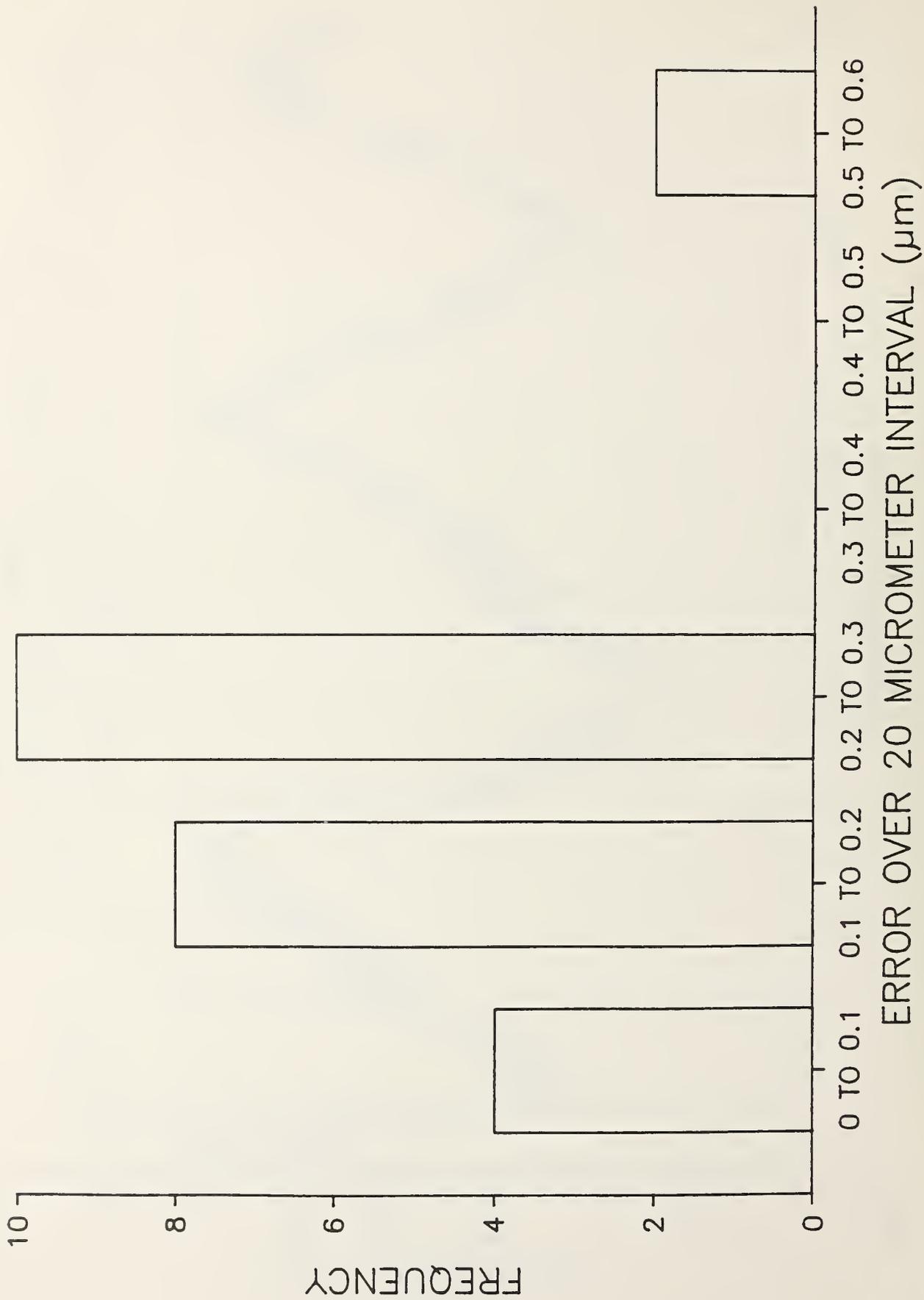


Figure 27. Data from laser interferometer showing error in stage position.

Welcome to the Melles Griot Nanomotion System  
 Copyright 1986, 1987 Melles Griot, All Rights Reserved  
 Nanomover software version 1.1

Turn the Nanoamp Chassis POWER switch ON ...  
 Press any key when done

Move            Change            Program            Files            Setup            Quit  
 Move motors

Axis	Motor	Position	Units	Motion Type
X Repeat Fast	2	8,771.200	microns	Repeat
Y Repeat Fast	3	12,029.799	microns	Repeat
Z Repeat Fast	1	12,512.000	microns	Repeat
X Repeat Med	2	8,771.200	microns	Repeat
Y Repeat Med	3	12,029.799	microns	Repeat
Z Repeat Med	1	12,512.000	microns	Repeat
Z Joq	1	12.512 000	mm	Joq
X Repeat Slow	2	8,771.200	microns	Repeat
Y Repeat Slow	3	12,029.799	microns	Repeat
Z Repeat Slow	1	12,512.000	microns	Repeat
X Tab	2	8,771.200	microns	Tab
Y Tab	3	12,029.799	microns	Tab
Z Tab	1	12,512.000	microns	Tab
X Absolute	2	8,771.200	microns	Absolute
Y Absolute	3	12,029.799	microns	Absolute
Z Absolute	1	12,512.000	microns	Absolute

Figure 28. Nanomover configuration options.

Edit Copy Quit  
 Use Return to select axis to edit

Axis  
 X Repeat Fast  
 Y Repeat Fast  
 Z Repeat Fast  
 X Repeat Med  
 Y Repeat Med  
 Z Repeat Med  
 Z Joq  
 X Repeat Slow  
 Y Repeat Slow  
 Z Repeat Slow  
 X Tab  
 Y Tab

```

Nanomover Parameters
Type new value, arrow keys to move, ESC to exit
X Repeat Fast
Position: 8,771.200
Axis Name: X Repeat Fast Motor #: 2 Units: microns
Motion Type: Repeat Plus Key: W Minus Key: Q
Base velocity: 62.500 Position Lock Time: 10
Lost Motion: Disabled LM Direction: + LM Value: 1
Accel: 200,000.000 0 0 0
Vel: 3,000.000 0 0 0
Units to move: 10.000 Home Position: 0
Absolute LStop: 0 Absolute RStop: 25,000.000
-----Relative-----
Left Stop: 0 Rt. Stop: 25,000.000
TABS:
0 0 0 0
0 0 0 0
0 0 0 0
0 0 0 0
  
```

Edit Copy Quit  
 Use Return to select axis to edit

Axis  
 X Repeat Fast  
 Y Repeat Fast  
 Z Repeat Fast  
 X Repeat Med  
 Y Repeat Med  
 Z Repeat Med  
 Z Joq  
 X Repeat Slow  
 Y Repeat Slow  
 Z Repeat Slow  
 X Tab  
 Y Tab

```

Nanomover Parameters
Type new value, arrow keys to move, ESC to exit
X Repeat Med
Position: 8,771.200
Axis Name: X Repeat Med Motor #: 2 Units: microns
Motion Type: Repeat Plus Key: S Minus Key: A
Base velocity: 62.500 Position Lock Time: 10
Lost Motion: Disabled LM Direction: + LM Value: 2
Accel: 200,000.000 0 0 0
Vel: 3,000.000 0 0 0
Units to move: 1.000 Home Position: 0
Absolute LStop: 0 Absolute RStop: 25,000.000
-----Relative-----
Left Stop: 0 Rt. Stop: 25,000.000
TABS:
0 0 0 0
0 0 0 0
0 0 0 0
0 0 0 0
  
```

Figure 29. Nanomover configuration options.

Edit Copy Quit  
 Use Return to select axis to edit

Axis  
 X Repeat Fast  
 Y Repeat Fast  
 Z Repeat Fast  
 X Repeat Med  
 Y Repeat Med  
 Z Repeat Med  
 Z Joq  
 X Repeat Slow  
 Y Repeat Slow  
 Z Repeat Slow  
 X Tab  
 Y Tab  
 Z Tab  
 X Absolute  
 Y Absolute  
 Z Absolute

Nanomover Parameters

Type new value, arrow keys to move, ESC to exit

X Repeat Slow  
 Position: 8,771.200

Axis Name: X Repeat Slow Motor #: 2 Units: microns  
 Motion Type: Repeat Plus Key: X Minus Key: Z  
 Base velocity: 62.500 Position Lock Time: 10  
 Lost Motion: Enabled LM Direction: - LM Value: 2

Accel: 200,000.000 0 0 0  
 Vel: 500.000 0 0 0

Units to move: 0.100 Home Position: 0  
 Absolute LStop: 0 Absolute RStop: 25,000.000

---

Relative

Left Stop: 0 Rt. Stop: 25,000.000

TABS:

0	0	0	0
0	0	0	0
0	0	0	0
0	0	0	0

Edit Copy Quit  
 Use Return to select axis to edit

Axis  
 X Repeat Fast  
 Y Repeat Fast  
 Z Repeat Fast  
 X Repeat Med  
 Y Repeat Med  
 Z Repeat Med  
 Z Joq  
 X Repeat Slow  
 Y Repeat Slow  
 Z Repeat Slow  
 X Tab  
 Y Tab  
 Z Tab  
 X Absolute  
 Y Absolute  
 Z Absolute

Nanomover Parameters

Type new value, arrow keys to move, ESC to exit

X Tab  
 Position: 8,771.200

Axis Name: X Tab Motor #: 2 Units: microns  
 Motion Type: Tab Plus Key: I Minus Key: U  
 Base velocity: 62.500 Position Lock Time: 10  
 Lost Motion: Enabled LM Direction: - LM Value: 2

Accel: 100,000.000 0 0 0  
 Vel: 500.000 0 0 0

Units to move: 0.050 Home Position: 0  
 Absolute LStop: 0 Absolute RStop: 25,000.000

---

Relative

Left Stop: 0 Rt. Stop: 25,000.000

TABS:

0	0	0	0
0	0	0	0
0	0	0	0
0	6,000.000	12,000.000	18,000.000

Figure 30. Nanomover configuration options.

Edit Copy Quit  
 Use Return to select axis to edit

Axis  
 X Repeat Fast  
 Y Repeat Fast  
 Z Repeat Fast  
 X Repeat Med  
 Y Repeat Med  
 Z Repeat Med  
 Z Joq  
 X Repeat Slow  
 Y Repeat Slow  
 Z Repeat Slow  
 X Tab  
 Y Tab  
 Z Tab  
 X Absolute  
 Y Absolute  
 Z Absolute

Nanomover Parameters

Type new value, arrow keys to move, ESC to exit

X Absolute

Position: 8,771.200

Axis Name: X Absolute Motor #: 2 Units: microns

Motion Type: Absolute Plus Key: 4 Minus Key: 3

Base velocity: 62.500 Position Lock Time: 10

Lost Motion: Enabled LM Direction: - LM Value: 2

Accel: 100,000.000 0 0 0

Vel: 2,000.000 0 0 0

Units to move: 0.050 Home Position: 8,000.000

Absolute LStop: 0 Absolute RStop: 25,000.000

---

Relative

---

Left Stop: 0 Rt. Stop: 25,000.000

TABS:

0	0	0	0
0	0	0	0
0	0	0	0
0	0	0	0

Nanomotion System

Melles Griot Nanomotion System  
 Program Terminated  
 Have A Nice Day!

Figure 31. Nanomover configuration options.

U.S. DEPT. OF COMM. <b>BIBLIOGRAPHIC DATA SHEET</b> <i>(See instructions)</i>	<b>1. PUBLICATION OR REPORT NO.</b> NBSIR 88-3092	<b>2. Performing Organ. Report No.</b>	<b>3. Publication Date</b> August 1988
<b>4. TITLE AND SUBTITLE</b> System for Measuring Optical Waveguide Intensity Profiles			
<b>5. AUTHOR(S)</b> Lee E. Larson, Donald R. Larson, Robert J. Phelan, Jr.			
<b>6. PERFORMING ORGANIZATION</b> <i>(If joint or other than NBS, see instructions)</i> NATIONAL BUREAU OF STANDARDS DEPARTMENT OF COMMERCE WASHINGTON, D.C. 20234		<b>7. Contract/Grant No.</b>	<b>8. Type of Report &amp; Period Covered</b>
<b>9. SPONSORING ORGANIZATION NAME AND COMPLETE ADDRESS</b> <i>(Street, City, State, ZIP)</i>			
<b>10. SUPPLEMENTARY NOTES</b> <input type="checkbox"/> Document describes a computer program; SF-185, FIPS Software Summary, is attached.			
<b>11. ABSTRACT</b> <i>(A 200-word or less factual summary of most significant information. If document includes a significant bibliography or literature survey, mention it here)</i> We have developed a computer controlled system to measure the intensity profile of optical waveguides. Knowledge of the intensity profile provides an indication of the shape of the waveguide, and therefore the degree to which light can be coupled to the guide from an optical fiber. This report describes the construction and operation of this system.			
<b>12. KEY WORDS</b> <i>(Six to twelve entries; alphabetical order; capitalize only proper names; and separate key words by semicolons)</i> computer control; coupling; mode intensity profile; optical fiber; optical waveguide			
<b>13. AVAILABILITY</b> <input checked="" type="checkbox"/> Unlimited <input type="checkbox"/> For Official Distribution. Do Not Release to NTIS <input type="checkbox"/> Order From Superintendent of Documents, U.S. Government Printing Office, Washington, D.C. 20402. <input checked="" type="checkbox"/> Order From National Technical Information Service (NTIS), Springfield, VA. 22161		<b>14. NO. OF PRINTED PAGES</b> 68 <b>15. Price</b>	





